

Desk-study on habitat quality for the European Sturgeon in the Dutch Rhine and southern North Sea

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Summary

One of the most endangered fish species worldwide is the European sturgeon *Acipenser sturio*. The River Rhine was home to an important sturgeon population that went locally extinct in the first half of the 20th century. In recent decades, many improvements of the ecological quality of the Rhine have taken place. Because the last remaining wild population of European sturgeon in the Gironde basin is very small and at considerable distance, it appears unlikely that rapid recolonization will take place if the Rhine is suitable again. That is why Stichting ARK, World Wildlife Fund (WWF) and the Dutch Anglers Association (Sportvisserij Nederland) have started a trajectory with the eventual reintroduction of the European sturgeon in the Rhine basin as the ultimate goal.

In this desk study, a first assessment is made of the habitat quality and areas available for the different life stages of European sturgeon in the Dutch part of the Rhine basin and the southern North Sea and connectivity between habitats based on available literature and environmental data. Furthermore, other possibilities and potential bottlenecks will be briefly discussed in view of an eventual reintroduction of the European sturgeon in the Rhine basin and southern North Sea.

European sturgeon already declined and disappeared in most of its distribution area long before field research on habitat requirements could be done. Therefore, not much is known on habitat use and requirements. Most is known on the habitat use of sturgeon in the Gironde estuary during their 2nd and 3rd year (Age 2 and 3), but data on habitat use and requirements are very scarce during their 1st year (age 1) and during the marine stages of older juveniles and adults. Because the data availability on environmental parameters and on habitat requirements strongly varies between the different water systems and life stages of sturgeon, two different modelling approaches were used to assess habitat quality for different life stages and water systems: 1) Habitat Suitability Index (HSI) Modelling for the freshwater and brackish habitats in the Dutch Rhine catchment area for juvenile sturgeons of age 1, 2 and 3 (i.e. up to about 60 cm length) based on salinity and water depth and 2) Dynamic Energy Budget (DEB) Modelling for the marine habitats in the Southern North Sea for age 4 and older juvenile and adult sturgeons, (for 80 cm sturgeons as a proxy for the juvenile stages that use marine habitats and 120 cm sturgeons for sturgeons on the onset of maturity) based on existing DEB-model for sterlet *A. ruthenus* adapted to European sturgeon for several life history parameters and using water temperature and benthic food production data.

Furthermore, an assessment of connectivity between habitats, e.g. where migration barriers are present and whether these are passable for European sturgeons, was made and an overview of fishing pressure in growing habitats is given based on published information and available datasets on fishing effort.

Freshwater and brackish habitat quality

The HSI model outcome indicate that large freshwater areas are available in the Lower Rhine water systems for growing during the age 1, but that brackish growing habitats for age 2 and 3 are very scarce (~300-500 ha). The HSI model is based on results from the Gironde estuary, a dynamic and tidal system. Whether juvenile sturgeons show the same preference for water depths in more stagnant waters like lake IJsselmeer and Haringvliet and running freshwater branches of the Lower Rhine remains unknown. Also in future scenarios with more extreme variants of the Haringvliet sluice regime, the brackish area remains limited. However, recent studies in the Elbe river indicate that juvenile European sturgeon move to more marine habitats already after the first growing season. Then one year old juvenile European sturgeons might be more flexible in what habitats they use for growing during their 2nd and 3rd year and marine habitats may serve as feeding grounds as well and the absence of brackish waters will not severely limit the possibilities for future reintroduction success. When 2nd and 3rd year juvenile sturgeons would also be able to use the freshwater lakes (e.g. IJsselmeer and Haringvliet),

which are absent in the Gironde, this might provide good feeding opportunities as well. Based on a literature overview and benthic food availability in soft sediments, IJsselmeer, Haringvliet and most parts of the Dutch Rhine branches provide good densities of benthic invertebrates that form the diet of juvenile sturgeons, e.g. chironomid larvae, worms and amphipods, except in the faster flowing sections with groyne fields where densities are much lower.

Marine habitat quality

The DEB modelling results based on water temperature and benthic food production in the North Sea area indicates good habitat quality for growing of juveniles and adult sturgeon in the southern North Sea and especially the coastal areas for juvenile sturgeons. And the relative habitat quality will even improve in the future given projected climate change. This is confirmed by the recapture of a European sturgeon released in the Elbe and caught in the Scheldt Estuary mouth that showed rapid growth (from 22 cm to 86 cm in 27 months). Habitat quality and food availability of the southern North Sea provides good opportunities for an eventual future reintroduction of the European sturgeon in the Rhine (and Elbe).

Migration barriers and connectivity between habitats

Connectivity between growing, wintering and spawning habitats for adult sturgeon are foreseen to be fairly good for entering the Rhine system in the near future. At present upstream migration is hampered at two of the three possible inlets to the Rhine basin. After 2018 it is foreseen that this will be improved greatly at the Haringvliet dam and Afsluitdijk dam at Kornwerderzand. The Nieuwe Waterweg is an open route without physical migratory barriers. In the Nederrijn, one of the three lower Rhine branches, upstream migration of adult sturgeons is likely to be hampered due to the small dimensions of the slots in the fishways. This is also the case for the fishways in the upstream part of the Rhine. The mainstream Rhine up until Iffezheim will be accessible for adult sturgeon. The fishways at Iffezheim and Gambshheim and in the main tributaries of the German and French part of the Rhine will be unsuitable for passage of large adult sturgeons due to the small size of the pools and narrow widths of the vertical slots between pools. Thus, potential suitable spawning grounds in the mainstream and small lower sections of the larger tributaries are accessible for adult sturgeons, but more upstream Iffezheim up to Basel and in the tributaries are not available for spawning. Whether this is a bottleneck for sustaining a future sturgeon population in the Rhine basin depends then on the area of suitable spawning area that is available downstream from Iffezheim. The quality and distribution of suitable spawning habitat for European sturgeon within the Rhine basin is largely unknown.

Downstream migration along the barriers in the Lower Rhine is relatively unhampered since they can move with the discharged water over the weirs or through the sluices. At present, only in the Nederrijn branch there is hydropower that may cause extra mortality for downstream movement of juvenile sturgeons. Adult sturgeons will not be able to pass the 10 cm gaps in the trash racks in front of the hydropower station. Juvenile sturgeons might however concentrate upstream from weirs or discharge sluices which make them more vulnerable to predation and may cause additional mortality.

Fisheries

Because sturgeons take a long time to become mature and get very old, extra mortality due to unnatural causes such as fishing is an important factor when reintroducing sturgeons. Fishing intensity in the North Sea area is high. This is confirmed by the pilot stocking and tagging experiment of 43 juvenile sturgeons in the Lower Rhine, where 14 % of the released sturgeons were reported to be caught along the Dutch coast within the first months, and not all bycatches will be reported. All bycatches were within the small beam trawl fishery and very close to the Dutch coastline. It is noteworthy that after sievenets were obliged in shrimp beam trawls, allowing escape of larger fish, no bycaught sturgeons were reported anymore. That all sturgeons were bycaught near the coast underlines the DEB modelling results that show highest habitat quality close to the coast, and also with the distribution of the fishing intensity of

small beam trawlers mainly targeting shrimp. When comparing the fishing intensity maps of the different fisheries and the habitat quality maps from the DEB modelling, the small beam trawl fishery and gill net fisheries probably most interfere with favourable juvenile sturgeon growing habitats. For the gillnet fishery, no recaptures were reported, either because of a lower catch rate in these gear type or due to an underreporting of bycatches in gillnets. In addition to catch rate and given the high fishing intensity in the North Sea area, an important factor will be the survival of sturgeons after being caught. These can vary highly for the different fisheries and within fisheries due to gear type and handling. To minimize impact of fisheries on European sturgeon several measures or mitigations can be taken: 1) Banning potentially harmful fishing gears that have high catch rates and low survival rates of European sturgeon, 2) Spatial and/or temporal closing of fisheries, 3) Lowering catch rates by providing selective escape devices in fishing gears or selectively deterring sturgeons from fishing gears, 4) Maximizing survival in fisheries by careful handling and optimizing releasing procedures of bycaught sturgeons.

Shipping

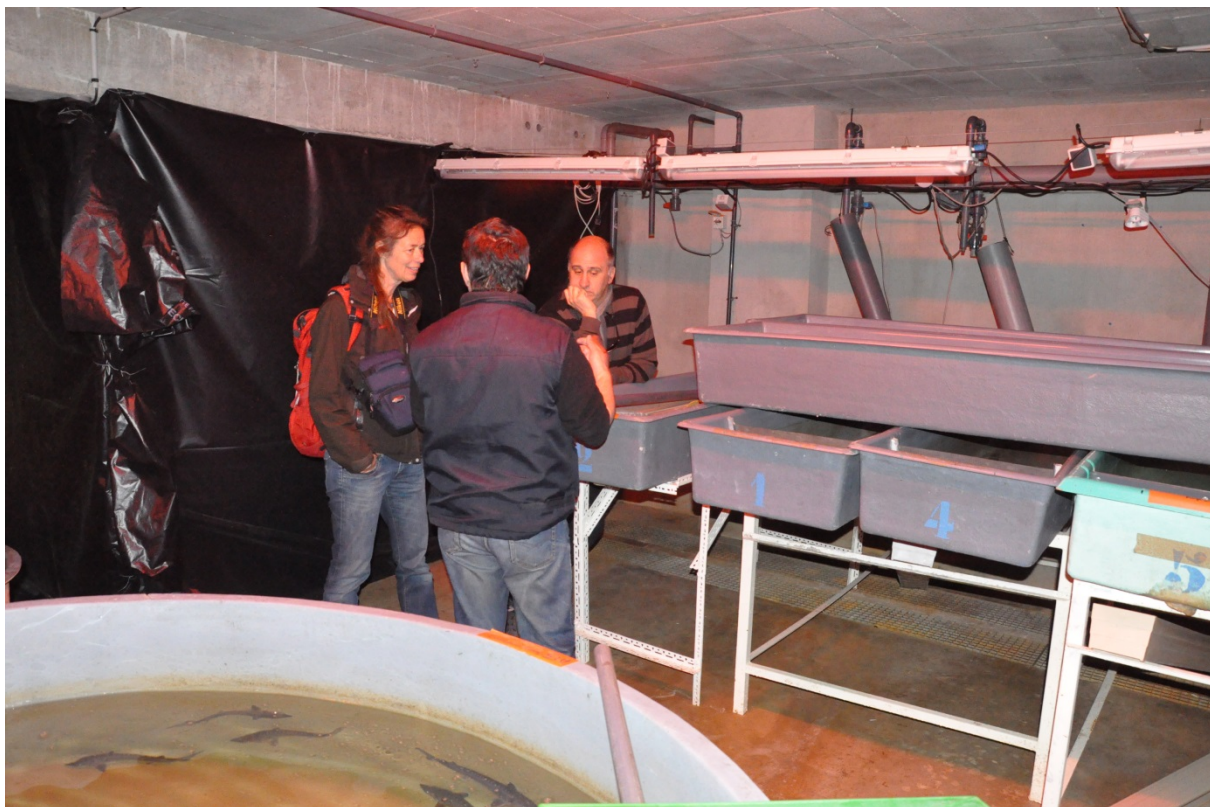
The Rhine is one of the most intensively shipped waterways in the world, especially the Waal branch which is the most important migratory branch for both adult and juvenile sturgeons. The pilot study with released juvenile sturgeon suggest that this might be a factor causing extra mortality due to propeller-strike. Other studies in North America indicate vessel strike and hitting by propellers as a possibly important source for unnatural mortality, but to what degree this is the case for the Rhine is unknown.

Climate change

The DEB modelling for temperature shows that the projected climate change may result in an increased relative habitat quality for juvenile sturgeons in the coastal areas of the southern North Sea. Another study provided indications that the relative importance of the Rhine as spawning river also increased under the projected climate change. The Rhine basin and adjacent coastal zones seems an important and promising area for restoring European populations in the future.

Recommendations

- An assessment of the available suitable spawning areas in the present Rhine basin in relation to the connectivity is needed to address whether additional habitat improvement is necessary or whether some barriers need to be made suitable for passage of adult sturgeon.
- Whether juvenile sturgeons need brackish habitats for growing or whether marine and freshwater habitats provide sufficient opportunities for successful growing during the first three years of their life can be studied by following the faith and habitat use of released test individuals of juvenile sturgeons of less than one year old.
- Because fishing mortality is an important potential bottleneck to the success of future reintroduction programs of European sturgeon it is essential to make an inventory and assessment of finding mitigation measures to minimize fisheries mortality. Experiences with European sturgeon and fisheries in the Gironde system can be taken into account, or best practices in other fisheries and sturgeon species. An impact assessment of the different fisheries in the southern North Sea can then be carried out. This can include different possible fishery management options and socio-economic approaches in close cooperation with fishermen.
- There are many potential opportunities, threats and unknowns for the reintroduction of European sturgeon. A desk study to prioritise these different factors will help to make future choices and allocation of efforts and funding during the next steps towards implementing a reintroduction program of European sturgeon in the Rhine basin.



European sturgeon rearing facility of IRSTEA (Cemagref) near the Gironde (photo Bram Houben)



Will a reintroduction programme of the European sturgeon in the Rhine be feasible in the near future? (photo Bram Houben)

1 Introduction

The European sturgeon *Acipenser sturio* is a critically endangered fish species that is on the brink of extinction in the wild (Williot et al. 2010). Historically, the Rhine catchment area housed an important sturgeon population that went locally extinct in the first half of the 20th century. The last adult sturgeons of the Rhine population were caught in the 1950s.

Many initiatives to improve the ecological quality of the Rhine catchment area have been undertaken in the last decades and the ecological status of the Rhine has greatly improved since. Given the distance to and small abundance of the last remaining wild population of European sturgeon in the Gironde basin, it is not expected that natural recolonization will take place in the near future when the Rhine might be suitable for European sturgeon again. Therefore, Stichting ARK, World Wildlife Fund (WWF) and the Dutch Anglers Association (Sportvisserij Nederland) started a trajectory aiming at the eventual reintroduction of the European sturgeon in the Rhine basin (Houben et al. 2012).

In view of an eventual future reintroduction of sturgeon, several research questions can be addressed:

In general:

What consequences will the return of the sturgeon in the Rhine basin have, e.g. on adjustments for fish passages, habitat quality and accessibility or shipping? To what extent are potential bottlenecks already solved?

Habitat related:

Is there sufficient habitat available in the main river of the Rhine and in the North Sea ranging from Belgium to Denmark?

North Sea and fisheries related:

What role does the coastal zone of the southern North Sea and the Wadden Sea play for (juvenile) sturgeon? What is the impact of currently existing fisheries on sturgeon? How can bycatch rates for endangered diadromous fish species as the sturgeon be reduced?

Goals for this desk study:

Based on available literature and environmental data and maps, a first assessment will be made of the habitat quality and areas available for the different life stages of European sturgeon in the Dutch part of the Rhine basin and the southern North Sea and connectivity between habitats. Assessment of spawning areas in the Rhine basin upstream of the Netherlands will not be addressed this study. In addition to this first assessment of habitat quality and connectivity, other possibilities and potential bottlenecks in relation to an eventual reintroduction of the European sturgeon in the Rhine basin and southern North Sea will be briefly discussed.



2 Literature overview on habitat and connectivity requirements of European Sturgeon

2.1 Habitat requirements during different life stages of European sturgeon

Short background overview of European sturgeon

The European sturgeon (*Acipenser sturio*) is an anadromous fish species. In the summer period adult sturgeons (age >12) migrate from the sea to spawning grounds located in the lower part of rivers (Fig. 2.1). Juvenile sturgeons (age 0-2) live in the freshwater rivers and migrate as sub adults (age 2-12) between the estuary and the open sea (Williot et al. 1997). Acolas et al. (2011) concluded in his review that the most well-known phase of the biological cycle corresponds to the period of growth in the lower estuary. Additional studies are still needed on migration tactics and also on young-of-year behaviour and habitat utilization in rivers and upstream estuary, as well as on reproduction activity and life at sea.

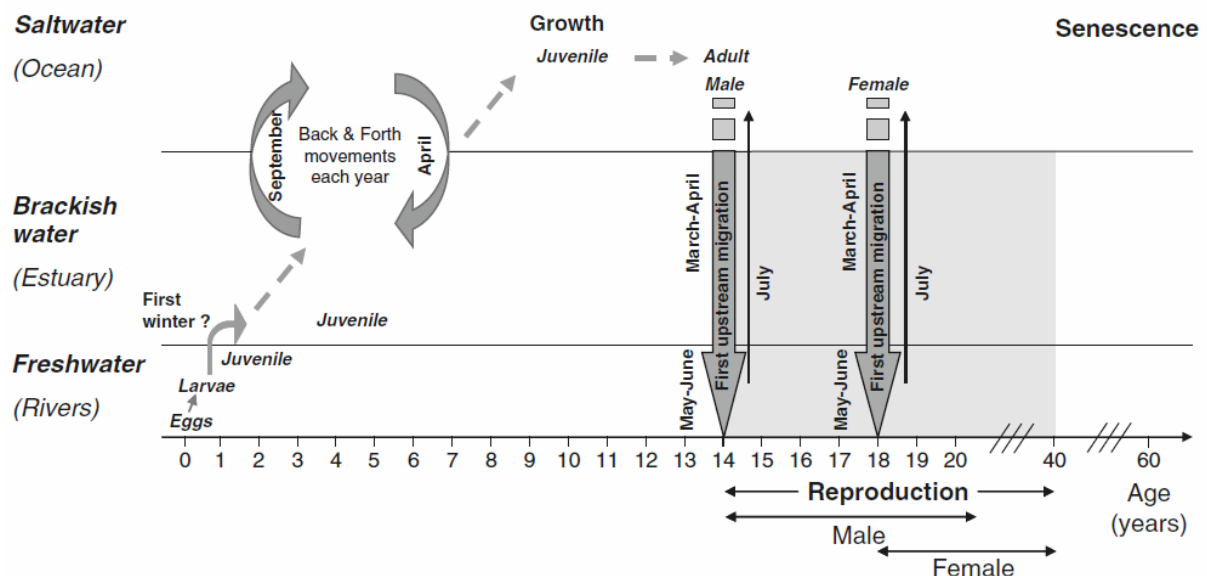


Figure 2.1. Biological life cycle of the European sturgeon *Acipenser sturio* in the Gironde system (France) (from Acolas et al. 2011)

Spawning

The life of European sturgeon starts in the freshwater rivers (Fig. 2.1). In the summer period adult sturgeons migrate from the sea to spawning grounds located in the lower part of rivers. Sturgeons mature relatively late. Age at maturity differs depending on the geographical area (Acolas et al. 2011). According to Magnin (1962) males are mature at age 12-15 and females at age 19-22. In the Gironde, sturgeon reaches maturity at ages between 10 and 12 years in males and between 13 and 16 in females (Williot et al. 1997). Once fish have found the relevant site, reproduction occurs between May and June (Magnin 1962).

Egg development

According to Acolas et al. (2011) knowledge of the biology of European sturgeon larvae and young of the year juveniles is scarce, due to the difficulty of investigating in the wild. A review by Acolas et al. (2011) and Kirschbaum and Williot (2011) showed that eggs are laid in the water column, and they are adhesive in order to stick rapidly to the substrate. Eggs hatch at about 3-4 days after fertilization at 8°C

and exogenous feeding start at day 16. The larval stage ends about one month after hatching, however exact timing still has to be determined.

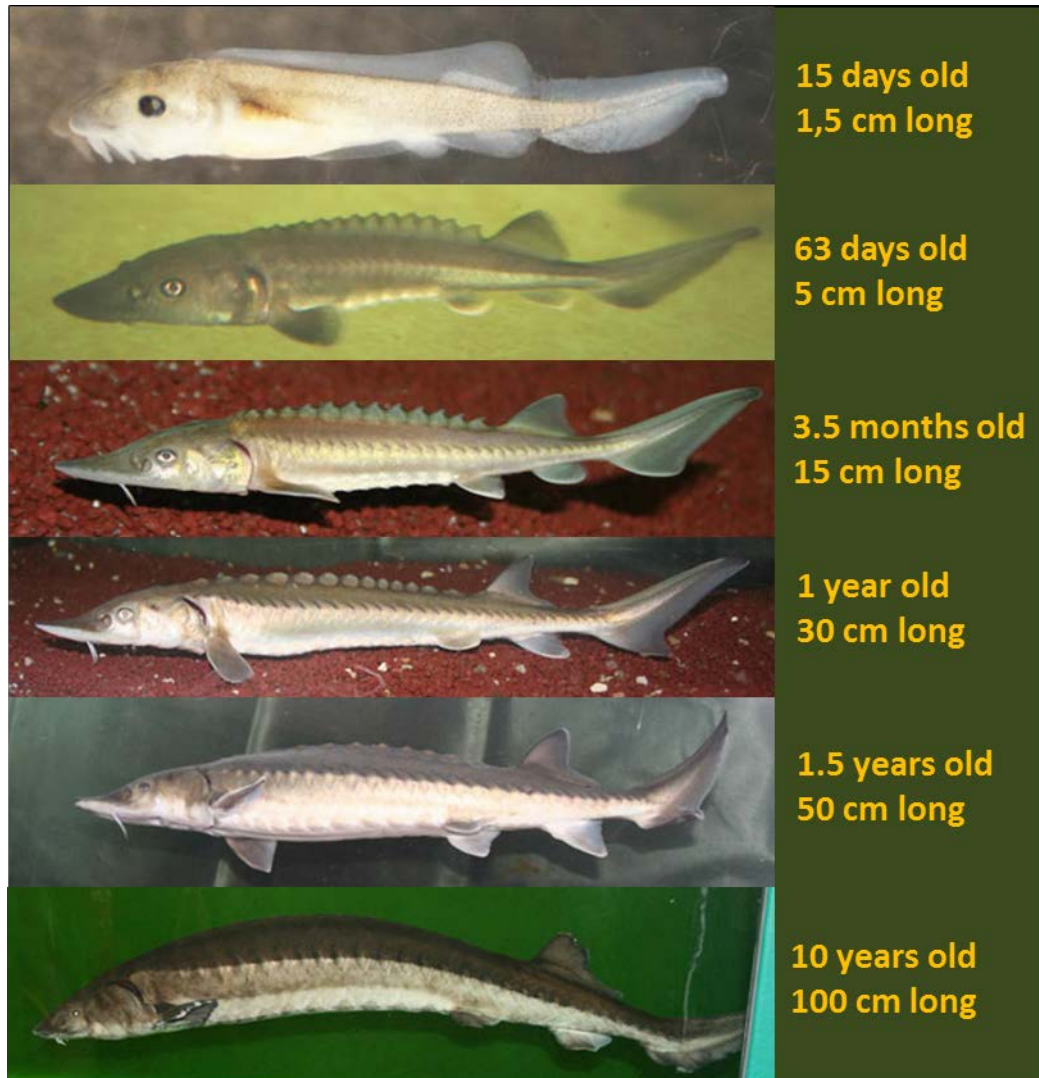


Figure 2.2. Development of European sturgeon during different life stages from larvae to adult (from Kirchbaum & Williot 2011).

Juvenile life stage in the river and upper estuary

Experimental studies on thermal behaviour by Charles et al. 2009 (in Acolas et al. 2011) and Staak et al. (1999) showed that juvenile showed dominant 24h activity rhythms with its maximum during night and colonize the water column. They also seem to prefer fine substrate (sand and gravel). Juvenile occupy the freshwater ecosystems and feed on worms (Oligochaeta), insect larvae, e.g. chironomids, and crustaceans (Gammaridae) (reviewed in Acolas et al. 2011).

Juvenile sturgeons leave the freshwater area and move into the estuary to enhance their growth. They may migrate for a while into the sea and then return to the estuary (de Groot 2002). This was seen in a recent unpublished study where juvenile fish of age 1-2 already migrated to the North Sea from the river Elbe (pers. Comm. J. Gessner). Other studies showed that catches of about 27 cm 1-year old fish were localized in the upper estuary by the end of their first winter (Rochard et al. 2001). Rochard et al. (2001) mentioned that no sturgeon under 46 cm has been captured in salinity above 2.5 ‰. However, as

Acolas et al. (2011) noticed, sampling occurs in only a few sectors of the estuary and not in the river; thus, juvenile downstream migration behaviour from the river to the estuary is largely unknown. It may be that some young juveniles may also occur in salty environments, as confirmed by unpublished results by Gessner in the Elbe river.

Juvenile Life in the Estuary and at Sea

However, according the review by Acolas et al. (2011), the juvenile phase in the estuary may be the best-known period in terms of habitat use, feeding regime and population dynamic. In the estuary sturgeons mainly feed on polychaeta and some crustaceans (Magnin 1962, Taverny 2002). In the Gironde estuary the juveniles (4-5 year) tend to congregate and stay in an area with an a depth of 7 m covering approximately 30 km² in the middle of the estuary where their favourite prey, polychaete worms, are located (Taverny et al. 2002). In the Gironde estuary the movements of juvenile sturgeons seemed to be related to the tidal current direction, seasonal movements seemed to be motivated by a search for warmer temperatures (Rochard et al. 2001, Taverny et al. 2002). After a period of early acclimatization of 15 months, juvenile sturgeons appear to be highly tolerant of salinity variations (Rochard et al. 2001). As shown in Fig 2.1 a regular back and forth movement between the lower part of the estuary and the sea has been observed with a seasonal rhythm (see review in Acolas et al. 2011). However, recent observations in the Elbe (unpublished results J. Gessner) this back and forth movement was lacking. According to several authors sturgeon entered the sea in the autumn and returned to the estuary in spring, but the reasons for this are not well-known (detailed review in Acolas et al. (2011)). Juveniles exhibit this behaviour up to about seven years old before remaining at sea definitively to continue their growth.

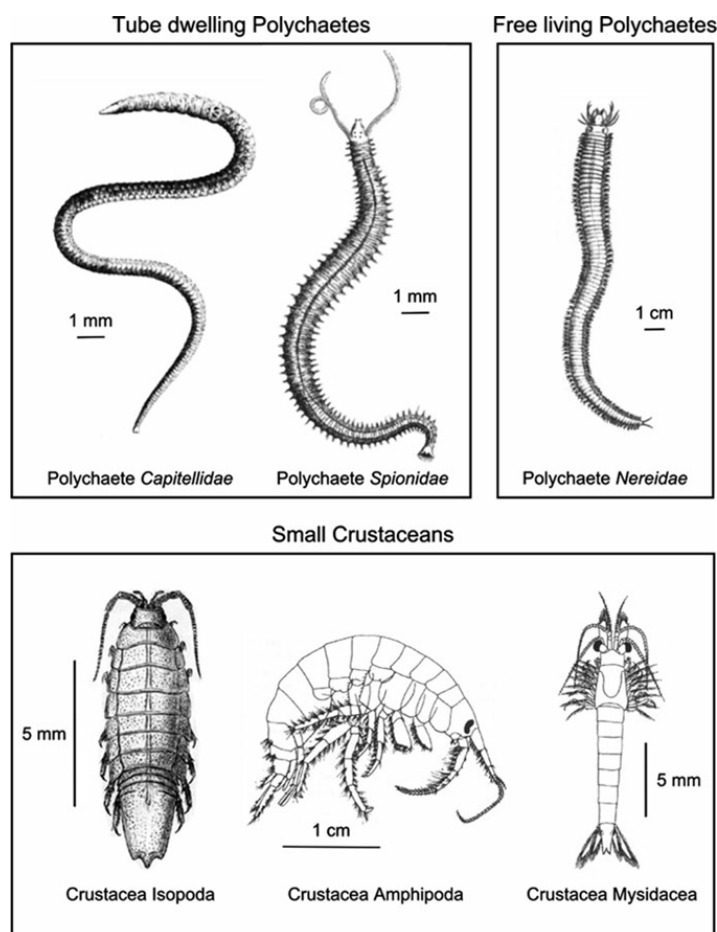


Figure 2.3. Prey organisms of juvenile European sturgeons in the Gironde Estuary (Brosse et al. 2011)

Adult Life at Sea and Reproductive Migration

Knowledge of life at sea is very limited and restricted to a few reports on incidental captures, and displacements between estuary and coastal areas have yet to be documented (for detailed review see Acolas et al. (2011)). A telemetry study by Breve et al. (2013) showed that sturgeons were recaptured by shrimp fisheries along the coast by beam trawlers. Rochard (1997) mentioned that captures of adult sturgeons occurred at depth over 100 m but according the review by Williot et al. (2011) the main distribution is restricted to the continental shelf at depths between 10-40 m based on capture data. Once adult sturgeons mature, adults leave the sea and enter the estuary during spring and early summer to begin their upstream migration to the spawning grounds (Lepage and Rochard 1995). After reproduction, adults return to the sea by the end of July.

2.2 Recent information on habitat use of sturgeon in the Rhine and North Sea

During the last decades European sturgeon is only observed very rarely in the North Sea area. Up until recently these sturgeon must have originated from the last remaining wild population in the Gironde area. However, recently two pilot introductions of European sturgeon took place in the Netherlands in the Rhine (Breve et al. 2014) and the Elbe (Gessner et al. 2010).

There is hardly anything known on growth rates of European sturgeon in the southern North Sea. These are data on only one anecdotal observation of a tagged juvenile that was released in the Elbe catchment area. Sturgeon number 06863 was released in Stör River in Sleeswijk-Holstein on 26 May 2012. It was 22 cm and 38 gram at release. The fish came from a captive breeding program in Berlin: Internationale Gesellschaft zur Rettung des Störs (Breve & Houben 2014). It was recaptured at the Westerscheldt mouth in the week 20-27 September 2014 and measured 86 cm and 2750 gram. This indicates very good growing conditions in the southern North Sea (64 cm and 2712 g increase in 27 months).

In 2012, in total 43 juvenile sturgeon (ranging 69-84 cm total length) were implanted with a NEDAP transponder and a PIT-tag, an external WOT-tag was attached and the fish were released in the Rhine near the Dutch-German border (Breve et al. 2014). Of these, 26 were confirmed to move downstream past NEDAP detection stations (Fig. 2.4). The preferred route was via the Waal and the Nieuwe Waterweg outlet to sea. None were recorded to have past the Haringvliet sluices. In total 17 tagged sturgeons that were released were never detected (Breve et al. 2014).

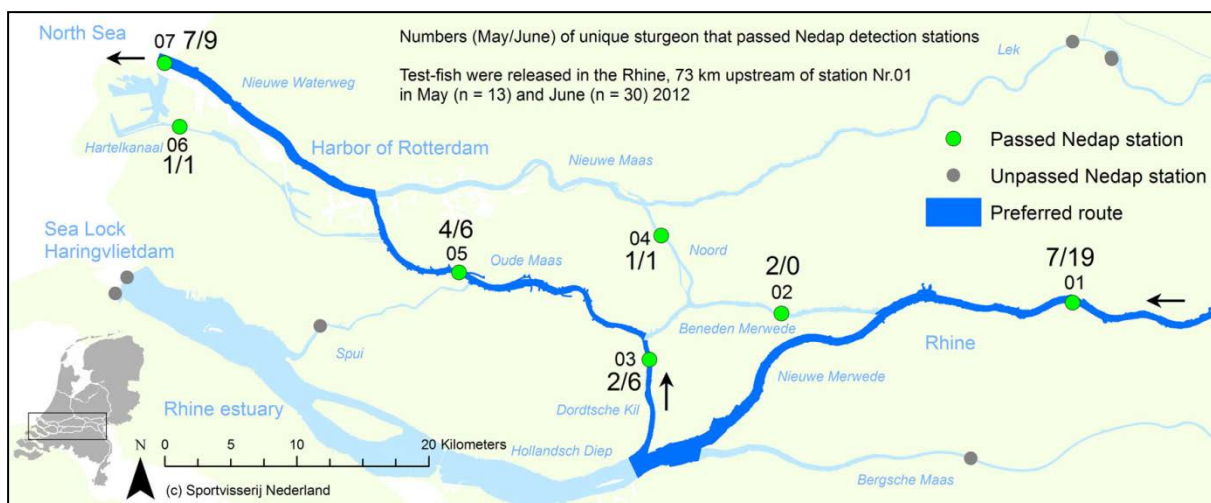


Figure 2.4. Overview of detections (*n* May/*n* June 2012) per NEDAP detection station of downstream migrating individual sturgeon that were released in the Rhine near Lobith (from Breve et al. 2014).

Of the 43 tagged sturgeons released within this pilot introduction study, six (14 % of the total) were recaptured along the Dutch coast (Fig. 2.5). Between July 19 and August 20 in 2012, three sturgeons were recaptured from the North Sea and two from the Wadden Sea, all within ca. 5 km from the shore where water depths are less than 25 m. These data were obtained from commercial fishermen, fishing for shrimps with beam trawlers. On October 30, a sixth sturgeon was reported from the North Sea. Five sturgeons were released alive, and one sturgeon died from a big stone picked up by the trawl net during trawling. Three of these recaptures were previously not detected with the NEDAP Trail® system, suggesting that part of the downstream migrating sturgeons were not detected. In total, 19 tagged sturgeons were confirmed to have moved into the North Sea.



Figure 2.5. Locations of report recaptures of European sturgeon, originating from two subsequent releases in 2012 of 43 sturgeon in total in the River Rhine (yellow square), the different groups of recaptured sturgeon are given in the legend (from Breve et al. 2014).

De Kok & Meijer (2012) performed a desk-study on habitat availability in the Rhine catchment basin. In the current situation, habitat with brackish water is scarcely available, especially when compared to the historical situation when the Rhine and Meuse estuary was still intact. Nowadays, the only brackish areas

in the entire Rhine catchment area are present in highly artificial water systems: the main outlet of the Rhine through the Rotterdam Harbour, the Nieuwe Waterweg and the canal Noordzeekanaal (Fig. 2.6).

In the near future (after 2017) the management of the discharge sluices at the Haringvliet will be altered in such a way that periodically water from the seaside will be allowed to enter the Haringvliet basin (an important outlet of the Rhine river) known as 'Haringvliet op een Kier'. This measure will improve the opportunities for upstream fish passage since at present the sluices are opened during 88 % of the tides during ebb (seaward flowing direction) and 0 % during flood (inland directed flow), whereas after the 'Haringvliet op een Kier' measures are implemented there will be some incoming water from the sea during 73 % of the tides on average. This will mainly affect migratory opportunities, but there will be hardly no increase in brackish water habitat. Only a small area will be temporarily brackish alternating with freshwater conditions (de Wit et al. 2011).

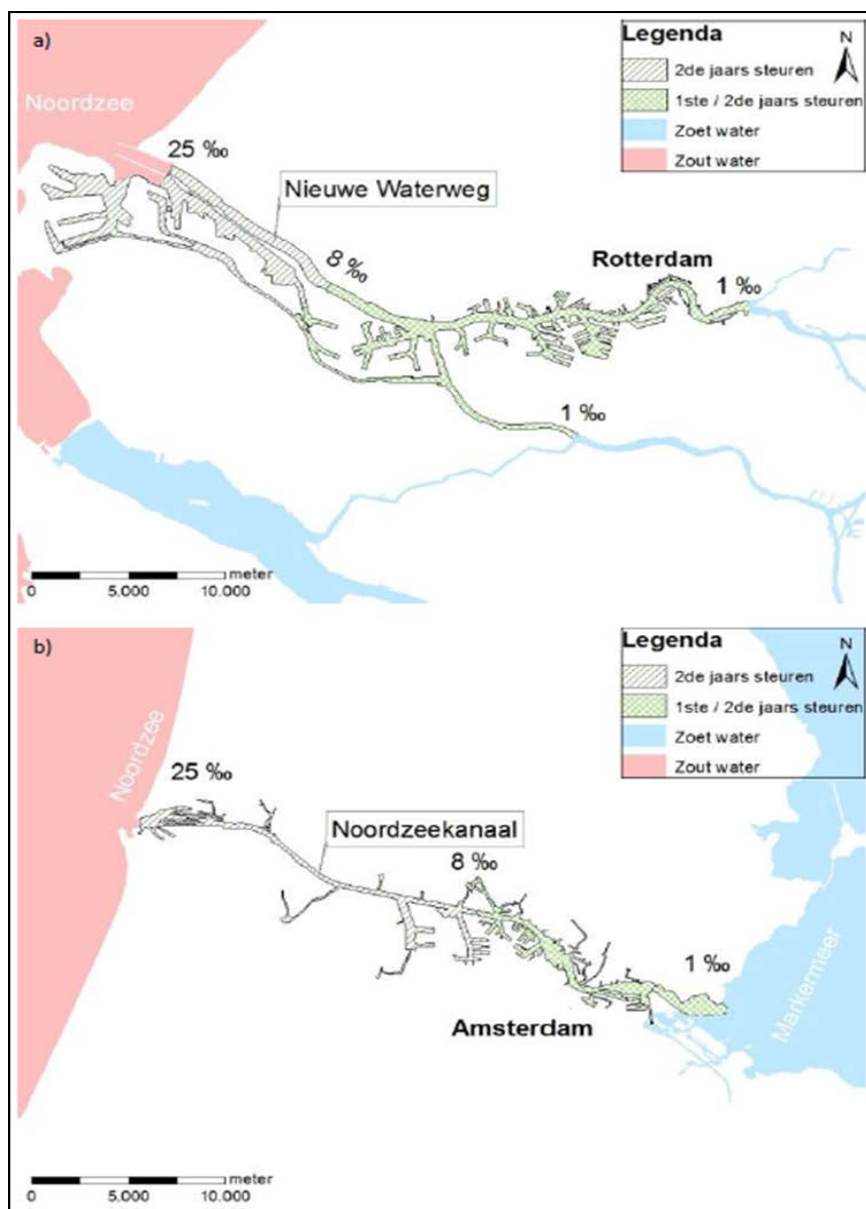


Figure 2.6. Within the Rhine catchment basin in the current situation, brackish habitats limited to two highly artificial water systems: the main outlet of the Rhine through the Rotterdam Harbour, the Nieuwe Waterweg (a) and the canal Noordzeekanaal (b) (Adapted from De Kok & Meijer, 2012).

Legend is in Dutch, meaning:

2^{de} jaars steuren = 2nd year sturgeon

1^{ste}/2^{de} jaars steuren = 1st/2nd year sturgeon

Zoet water = Freshwater

Zout water = Saltwater.

Noordzee = North Sea

3 Material and Methods Habitat Modelling and Connectivity

Based on habitat use during different life stages from literature, mainly originating from the Gironde area age 1 sturgeon use freshwater habitats, age 2 and 3 juvenile sturgeons use brackish estuarine waters and age 4 and older sturgeon use marine habitats for growth. We therefore chose a two-step modelling approach to indicate habitat suitability for the Rhine catchment area and southern North Sea:

- 1) Modelling habitat suitability of the freshwater and brackish habitats in the Dutch Rhine catchment area for juvenile sturgeons of age 1, 2 and 3 (i.e. life stages up to about 60 cm in total length) (see paragraph 3.1).
- 2) Modelling habitat suitability of the marine habitats in the Southern North Sea for age 4 and older juvenile and adult sturgeons, where we modelled suitability for 80 cm sturgeons as a proxy for the juvenile stages that use marine habitats and 120 cm sturgeons for sturgeons on the onset of maturity (see paragraph 3.2).

Because the data availability on environmental parameters and on habitat requirements strongly varies between the different water systems and life stages of sturgeon, different model approaches for 1) habitat Suitability Index modelling, and for 2) Dynamic Energy Budget: DEB were performed.

3.1 Habitat modelling of the Dutch Rhine basin (age 1-3)

The habitat suitability study for sturgeon in the Dutch large rivers is based upon three age classes, as their habitat use differs as based on literature and these juvenile stages use fresh and/or brackish water as growing habitats. The classes used are: age 1 (first year), age 2 (second year) and age 3+ (all remaining juvenile stages). Little is known on habitat preference and relation to different parameters for juvenile sturgeons, especially during the first year (age 1). For the second and third year (age 2 and 3) more data is available, mainly from the Gironde estuary.

As a map of river depth of all rivers is not available an ecotope map was used to assess the habitat suitability of the rivers for sturgeon (RWS ecotopen_CC3). A benefit of this particular map is that multiple variables are available, which could be of importance for the suitability for sturgeon. An example is the variable 'vegetation', which sturgeon avoids. Vegetated ecotopes can therefore be removed from the suitability selection; which with only a depth map available would not have been possible. Salinity is also one of the variables present in the ecotope map, which plays an important role in the suitability of waters for sturgeon. A drawback of the ecotope map is that the values of the variables are classified, and hence only the given classification can be used.

For all age categories the suitability was assessed based on water depth (table 3.1) and salinity (table 3.2). The degree of suitability is based on the literature at hand. The classification of the map is thereby leading and nuance is not an option. A selection based on the variable 'zone' was done prior to the selection based on salinity and water depth. The zone 'aquatic' was selected as suitable for age 2 and age 3+, while in addition to 'aquatic' also the zone 'shore - wet' was selected for age 1 sturgeon. These shores are classified as dynamical and submerging and contain the ecotopes 'shallow water' and 'freshwater sand / mud flat'. In addition, the ecotope 'water behind bank' ('water achter vooroever') was taken into account for first year sturgeon. In contrast, water basins were not considered suitable for any sturgeon age class and hence the suitability of the variable 'dynamic' was set to zero in case of 'low' dynamics.



European sturgeon age 1, during its first year (Photo Bram Houben)

Table 3.1. Suitability of the water depth classes as present in the used ecotope map for the three age categories for sturgeon. The depth classes hold for the zone 'aquatic' and 'shore - wet'. Classification is given in meters if available from the publication 'Ecotopenkartering Rijntakken-Oost 3^e cyclus (2008-2012) 1 december 2011'.

Water depth	Age 1	Age 2	Age 3+
Shore - wet	1	0	0
shallow (-0.3 – 1)	1	1	0
Moderately deep (1 – 3)	1	1	0
Deep (3 – 5)	1	1	1
Very deep/deep	0	0	0
Very deep (>10)	0	0	0

For those ecotopes falling in the category 'depth unknown' a selection was made based on other ecotope characteristics, such as salinity. For example, harbours are classified as 'depth unknown' and 'fresh water' and are therefore considered suitable for age 1 sturgeon but not for older sturgeon. The degree of suitability of harbours based on shipping intensity was not considered.

Table 3.2. Suitability of the salinity classes as present in the used ecotope map for the three age categories for sturgeon. Categories were taken from Van der Molen et al. Salinity is given in g CL/l.

Salinity	Age 1	Age 2	Age 3+
fresh (< 0.3)	1	0	0
Weakly brackish (0.3 – 3)	1	1	0
Fresh/weakly brackish	1	1	0
Fresh/weakly brackish/brackish	0.5	1	0
brackish (3 – 10)	0.2	1	1
Brackish/salt (10 – 18)	0	0	1

The resulting overall suitability of an ecotope is the lowest value of the different variables combined. Thus, if for an ecotope the habitat suitability (HSI) based on salinity equals one, yet based on water depth equals zero, then the overall suitability equals zero.

An overview of the areas per salinity and water depth classes, not considering suitability, already makes clear that little habitat with brackish water is present in the Dutch river system (table 3.3). This overview shows the current maximum area available, not considering other factors. For the variable water depth it becomes clear that the largest areas are 'deep' or 'moderately deep', combined with fresh water. This area is, given the preferences of non-fresh water waters, not available for older sturgeon.

Table 3.3. Area (in ha) for combinations of salinity and water depth. The category 'depth unknown' contains the ecotopes: harbour, brackish connected lake, brackish water behind bank, fresh water behind bank, fresh water connected lake and river-guiding water (<20d/y flooded)

	Deep	Moderately deep	Shore-wet	Unknown	Shallow	Very deep	Very deep/deep
Brackish	207	80		4	37	757	
Brackish/salt			20				
Fresh	140762	30176	1255	5723	6859	57755	8058
Fresh/weakly brackish			2461				
Weakly brackish	121	18			7	384	

Another important factor in habitat quality is food availability. Due to its rarity, very little is known about the diet and food preferences of the European sturgeon. Especially for sturgeon of age class one, data on diet and food preferences is largely lacking. For the age classes 2 and 3 more knowledge on diet and food preferences is available, but mainly from the Gironde system, where the juvenile age 2 and 3 sturgeon concentrate in three zones distributed along a salinity gradient. These habitats form an important feeding ground rich in tube dwelling polychaetes (*Polydora* sp. and *Heteromastus filiformis*), which have been the dominant prey items of European sturgeon juveniles (Brosse et al. 2011).

There is an ongoing long-term monitoring program on macrofauna at fixed locations in the main water systems (MWTL). However, data on food availability in the different Rhine branches are not readily available in maps or at fine resolution. There are several large combined databases with macrofauna data in the Dutch water systems; i.e. BIS (Benthos Information System) from monitoring, effect and PhD projects from NIOO-CEME and RWS database with RIZA projects and MWTL-monitoring results (see Wijnhoven & Hummel 2008). Analysing patterns and densities for different species groups of benthic invertebrates in the branches and freshwater and brackish water systems in the Dutch Rhine basin requires substantial effort and is beyond the scope of this study. Given the limited knowledge on diet and availability of spatial density information on benthic invertebrates, a more qualitative discussion on food availability in the freshwater and brackish parts of the Dutch Rhine basin will be given in the discussion.

3.2 Habitat modelling of the North Sea area (age 4+)

To predict potential growth habitat for sturgeon a physiological model (Dynamic Energy Budget: DEB) model was linked to an ecosystem model (GETM-ERSEM) to examine the physiological-based habitat utilization of European sturgeon. For detailed description of model use see Teal et al. (2012). Temperature data were available from the ERSEM North Sea model on a 10 x 10 km grid across the North Sea. Benthic productivity data were available from ERSEM on the same grid. Temperature and benthic production were then used as input into the DEB growth model to calculate scope for growth per ERSEM grid cell. The scope for growth was used as a proxy for habitat quality. The input of food followed a type II functional response curve (a curve with a decelerating rate, i.e. rectangular hyperbola).

The models were run for several scenario's (1989, 2002 and 2049; both winter and summer) to obtain maximum growth potential for sturgeon of 80 cm (about the size of juveniles that fully utilise marine habitats for growing) and 120 cm (about the size of onset of maturity). The 1989 and 2002 scenarios represent variation between years in the current situation. For future scenarios (2049) we used POLCOMS-ERSEM, a different underlying oceanographic model with same biological modules (ERSEM). The model was run for both temperature as well as for combined temperature and food. We adapted an existing DEB model for Sterlet *Acipenser ruthenus* (Table 3.4) for temperature tolerance of European

sturgeon (Niklitschek and Secor 2009) and calibrated the model (following methods of Teal et al. 2012) with field growth rate data on European sturgeon based upon recapture data from a study in the Elbe (Breve and Houden, 2014). Outcomes of the adapted DEB model were checked against available life history parameters for European sturgeon (Table 3.5). At present, there are insufficient data available to build a full DEB model for European sturgeon. For Atlantic sturgeon *Acipenser oxyrinchus* there are sufficient data available to build a full DEB model that could be adapted for metrics and some parameters for European sturgeon. Building, parameterising, calibrating and validating this DEB model, however, requires substantially more effort than was available within this study.

Table 3.4. DEB model for Sterlet *Acipenser ruthenus*. The lower and upper boundary tolerance range of temperature were adapted based upon Niklitschek and Secor (2009).

Parameter statistic	Value	Unit
max spec assimilation rate at T	152.58	J/d.cm ²
structural length at metamorphosis	0.11371	cm
allocation fraction to soma	0.978	-
vol-specific somatic maintenance at T	10.27	J/d.cm ³
reserve capacity	6237.93	J/cm ³
specific cost for structure	7848	J/cm ³
Arrhenius temp	6000	K
reference temp	293	K
lower boundary tolerance range	277	K
upper boundary tolerance range	301	K
Arrhenius temp for upper boundary	190000	K
shape coefficient	0.1214	-

Table 3.5. Life history parameters for European sturgeon *Acipenser sturio*

Parameter statistic	Value	Unit	Reference
length at maturity male	1200	mm	review in Emmerik (2004)
length at maturity female	1500	mm	"
age at hatching	3	day	review in Kirschbaum & Williot (2011)
age first feeding	16	day	"
age at metamorphosis	63	day	"
age at maturity male	13-15	year	review in Acolas et al. (2011)
age at maturity female	19-22	year	"
length at hatching	40-50	mm	Kirschbaum & Williot (2011), Jaric & Gessner (2013)
length at first feeding	15	mm	review in Kirschbaum & Williot (2011)
length at metamorphosis	40-50	mm	review in Williot et al. (2011)
length at maturity	1200-1800	mm	review in Kirschbaum & Williot (2011)
ultimate length observed	5000	mm	review in Williot et al. (2011)
ultimate wet or dry weight	800-1000	kg	Jaric & Gessner (2013)
max life span	100-120	year	"

3.3 Migratory barriers and connectivity in the Rhine basin

In the Rhine basin there are many migration barriers, e.g. sluices, weirs and hydropower stations. European sturgeons are restricted to deeper sections of the river and tributaries for spawning and do not penetrate into the catchment area and smaller shallower tributaries as far as for instance salmonids do. In the overview of migration barriers, we therefore focus on the lower Rhine branches in the Netherlands and the mainstream of the Rhine in Germany upstream to Basel. Although not much is known on the historical spawning grounds of European sturgeon in the Rhine basin, it is believed that this selection covers most of the main spawning grounds, except perhaps the lower reaches of the larger tributaries, e.g. Mosel and Main (Houben et al. 2012, de Kok & Meijer 2012).

An overview of all potential barriers in the main river system of the Rhine basin is given in Fig 3.1. From the sea, the main entrance will be the Nieuwe Waterweg at Rotterdam, since on average most discharge from the Rhine will flow through this waterway.

The Haringvliet sluices are an important inlet/outlet to the Rhine basin from/to sea, especially at higher discharges. The inlet/outlets at the Afsluitdijk, i.e. the discharge sluices at Den Oever and Kornwerderzand, are another route via the IJsselmeer and IJssel branch to the mainstream of the Rhine.

Theoretically adult sturgeons could also enter via the sluices in the Noordzeekanaal at IJmuiden and then progress either via the Amsterdam-Rijn Kanaal or via lake Markermeer and the sluices at Krabbegat or Houtrib to lake IJsselmeer (Fig. 3.1), but the unnatural flow conditions and directions and the different shiplocks present on the routes make this a highly unlikely route to be used. Other diadromous species that move upstream the Rhine for spawning such as Atlantic salmon and Sea trout never used these routes during tagging programmes 1998-2014 with NEDAP telemetry (Bij de Vaate et al. 2003, Breukelaar unpublished data).

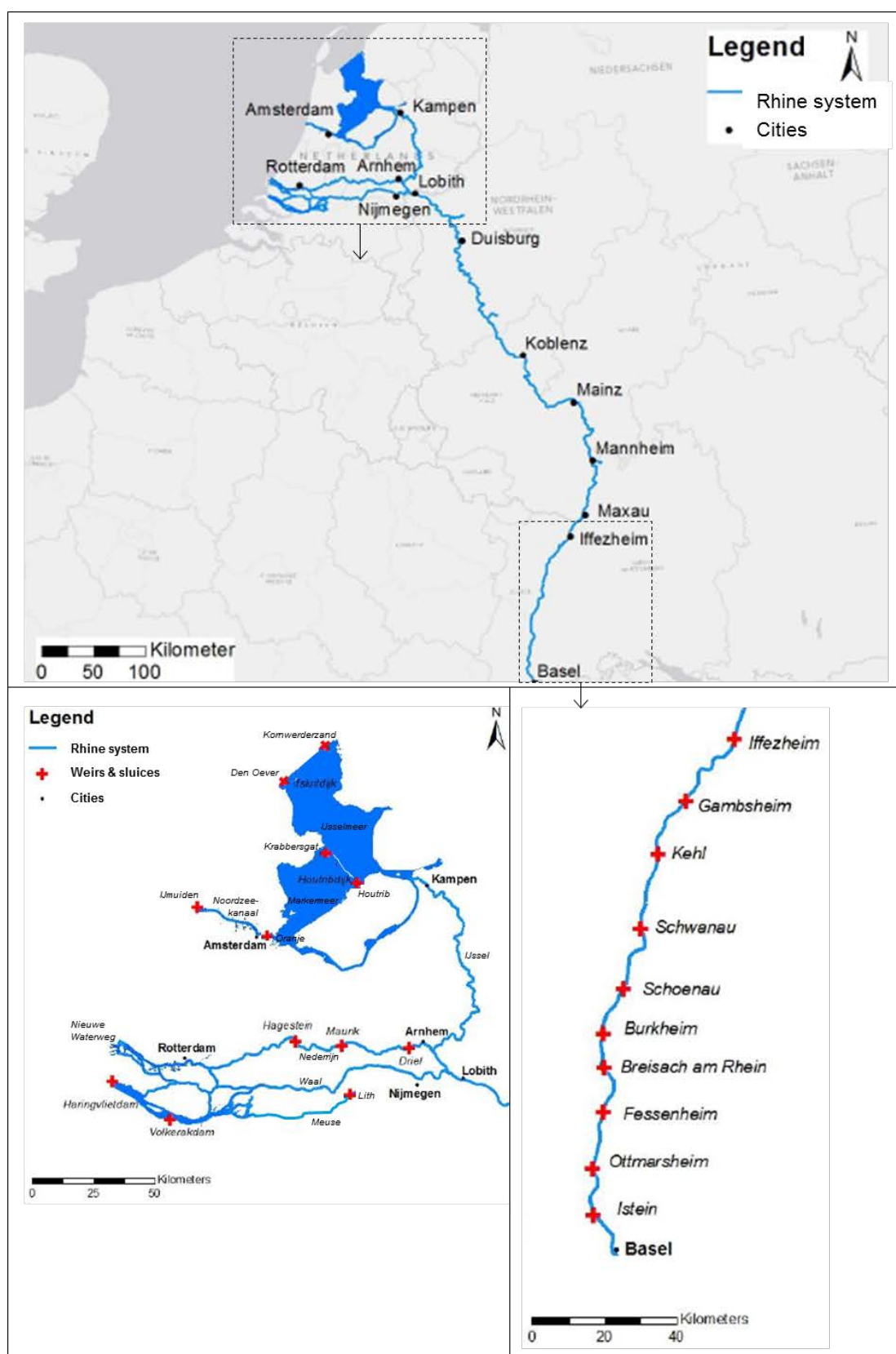
In the lower Rhine branches, there are only weirs in the Nederrijn-branch, which runs parallel to the Waal-branch. These three weir-complexes (at Hagestein, Amerongen and Driel) exist of a weir, a ship lock and a fishway. At Amerongen and Hagestein there is also a hydropower station, although the hydropower station at Hagestein is out of order for years already.

The branches Waal and IJssel are free from barriers. The River Rhine is free from barriers up to Iffezheim. From Iffezheim to Basel there are ten weir-shiplock-hydropower complexes. Of these, only alongside the first two barriers at Iffezheim and Gamsheim are fishways constructed.

The main migratory barriers for sturgeon are:

- 1) From sea entering the Rhine basin:
 - Haringvliet discharge sluices
 - Afsluitdijk discharge sluices at Den Oever and Kornwerderzand
- 2) In the lower Rhine branches:
 - Weir-complexes in the Nederrijn branch at Hagestein, Amerongen and Driel
- 3) In the mainstream of the Rhine:
 - Ten weirs/dam complexes between Iffezheim and Basel, of which Iffezheim and Gamsheim are the first two, and the only ones that are provided with fishways at present.
- 4) In the tributaries of the Rhine:
 - Many weirs/dams with or without hydropower stations, these are less relevant for sturgeon since they mostly give access to shallower streams that are not suitable for spawning of sturgeon.

For the barrier assessment and connectivity analysis in this report we mainly focus on 1, 2, 3 and the main tributaries of the Rhine under 4, where we treated the river Meuse as a tributary since they share the same delta. The main tributaries Meuse, Lippe, Ruhr, Sieg, Mosel, Lahn, Main and Neckar were taken into account.



A summary of the technical characteristics of the fishways in the Lower Rhine branch and in the upper Rhine in Germany are compared to the fishway built in the lower Elbe at Geesthacht (Menzel & Schwevers 2012, Lehmann *et al.* 2012). The latter was specifically designed to also facilitate passage of adult sturgeons of 3 m length. During monitoring of fish passage in the double vertical slot pool type fishway at Geesthacht, two Siberian sturgeons *A. baeri* (an exotic species in the Elbe river) were found to successfully have passed the fishway (Adam *et al.* 2012). The estimated suitability of the different fishways and sluice regimes for passage of adult sturgeon will be discussed in the results.

Table 3.4. Overview of technical characteristics of the different fishways in the Rhine compared to the fishway Geesthacht in the Elbe that was designed to facilitate passage of large sturgeons

River system	Lower Rhine branch Nederrijn			German Rhine		Elbe
Name location	Hagestein	Amerongen	Driel	Iffezheim	Gambsheim	Geesthacht*
Fishway type	V-stepped pool type	V-stepped pool type	V-stepped pool type	Vertical slot pool type	Vertical slot pool type	Double vertical slot pool type
Discharge at entrance fishway	1-4 m ³ /s	1-4 m ³ /s	1-10 m ³ /s	3-5 m ³ /s	3-5 m ³ /s	>13 m ³ /s
Discharge fishway	1-4 m ³ /s	1-4 m ³ /s	1-10 m ³ /s	~1.2 m ³ /s	~1.2 m ³ /s	~5.6 m ³ /s
Number pools	23	23	18	37	39	49
Length pool	> 9 m	> 9 m	> 10 m	4.5 m	4.5 m	9 m
Width pool	10 m	10 m	16 m	3.3 m	3.3 m	16 m
Depth pool	> 1.4 m	> 1.4 m	> 1.4 m	1.50 m	1.60 m	1.70 m
Step level differ.	0.16 m	0.16 m	0.15 m	0.25 m	0.25 m	0.09 m
Width slot at step	~0.30 m	~0.30 m	~0.30 m	0.45 m	0.45 m	1.20 m
Height slot at step	1.4-2.0 m	1.4-2.0 m	1.4-2.0 m	1.50 m	1.60 m	1.70 m

* Largest fishway in Europe in the Elbe, designed to also facilitate adult sturgeons of 3 m, and monitoring showed that exotic sturgeon species successfully passed this fishway (Menzel & Schwevers 2012, Lehmann *et al.* 2012, Adam *et al.* 2012).

A front view scheme of the steps in the fishways at Hagestein and Amerongen is given in Fig. 3.2. An impression of the steps and fishways at Amerongen and Iffezheim is given in Fig. 3.3.

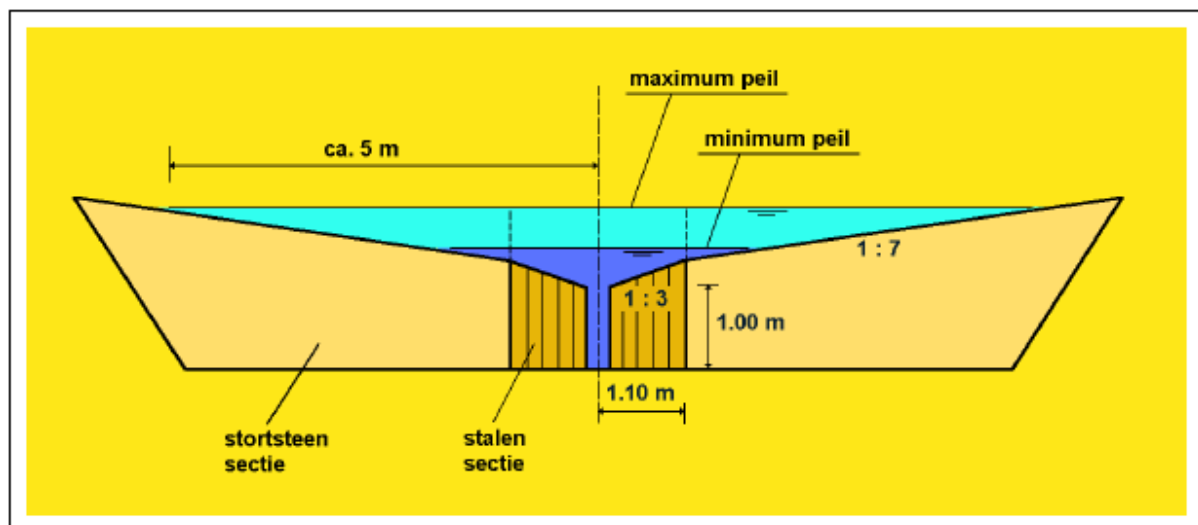


Figure 3.2. Front view of V-shaped step in the V-stepped pool fishways of Hagestein and Amerongen (from Schropp 2011).



Figure 3.3. Photographic impression of the fishway steps at Amerongen (top left) and Iffezheim (bottom left), and top views on the fishways at Amerongen (top right) and Iffezheim (bottom right). The fishways at Hagestein and Driel are very similar to Amerongen. The fishway at Gambenheim is very similar to Iffezheim.

Also in the main tributaries many barriers such as dams with hydropower, weirs and shiplocks are present. Some of these are facilitated with fishways. An overview of the most downstream situated barriers and characteristics of the fishways at these sites are given in table 3.5.

Table 3.5. Overview of the main tributaries of the Rhine and the location and type of the most downstream situated barriers and fishways (HPS= Hydro Power Station).

Tributary	Meuse	Lippe	Ruhr	Sieg	Mosel	Lahn	Main	Neckar
Location	Lith	Werne	Mülheim	Buisdorf	Koblenz	Lahnstein	Kostheim	Ladenburg
Fishway type	V-stepped pool type	Nature pool type	Fish ramp + sluice	Nature like fish ramp	Vertical slot pool type	Pool type overflow	Orifices pool type	Vertical slot pool type
Barrier type	Weir HPS Shiplock	Weir	Weir HPS Shiplock	Weir	Weir HPS Shiplock	Weir HPS Shiplock	Weir Shiplock	Weir HPS Shiplock
Flow at step	Shallow overflow	Shallow overflow	Shallow overflow	Shallow overflow	Slot 0.45 m wide and 1.2 m high	Shallow overflow	Small orifices	Slot <0.4 m wide

Criteria for successful passage of fishways by sturgeons

Because the European sturgeon has already strongly declined in historical times before fishways were constructed and is currently extremely rare, little is known on their requirements for successful passage through fishways. Also for other sturgeon species information on successful ascent through fishways and factors determining the success rate are rare (Kynard et al. 2011). Most information is available for Lake Sturgeon (*Acipenser fulvescens*), Shortnose Sturgeon (*Acipenser brevirostrum*) and White Sturgeon (*Acipenser transmontanus*), all North-American species (Parsley et al. 2007, Kynard et al. 2011).

Little is known on swimming performance of European sturgeon. In general, sturgeons are poorer swimmers than salmonids, especially at burst swimming (Peake et al. 1997). Sturgeons also generate more drag while swimming and have a less efficient tail than salmonids.

Kynard et al. (2011) defines the following key factors for a sturgeon fishway (mainly determined for the smaller sized species Lake Sturgeon and Shortnose Sturgeon):

- Continuous flow not exceeding two body lengths s^{-1} .
- No full cross-channel walls.
- Abundant eddies or wider pools for resting.
- Acceptable water depth (at least two body width deep, but preferably deeper).

Warren & Beckman (1993) and Parsely et al. (2007) found that in the Columbia basin White Sturgeons seldom ascended existing fishways, probably because these were designed primarily for anadromous salmonids. Some successful passage occurred in fish lifts. In addition to the different swimming behaviour and capacity of sturgeons when compared to salmonids, also the large body size, White Sturgeons can grow up to 6 m in length, severely limited passage opportunities through submersed orifices and vertical slot pool type fishways. Most successful passage of White Sturgeons occurred at Dalles Dam, and only in one of the two fishways present. The East fishway had submerged orifices of 0.66 m width x 0.66 m height, whereas the North fishway had orifices of 0.46 x 0.46 m. Pool width was 9.14 m vs. 7.32 m and pool length was 4.67-4.88 m vs. 4.27-4.88 m. White sturgeons up to 207 cm successfully passed the East fishway. These studies state that White Sturgeons are reluctant to pass overflows and need wide orifices or vertical slots and widely spaced pools for successful passage.

The fishway at Geesthacht in the Lower Elbe was specifically designed to also facilitate passage of adult European sturgeons of 3 m length (Menzel & Schwevers 2012, Lehmann et al. 2012), which resulted in widely spaced vertical slots (120 cm wide), large pools (16 m width x 9 m long x 1.7 m deep), and small drops between pools (0.09 m) to limit water velocity, see also table 3.4.

4 Habitat Modelling Results

4.1 Habitat modelling of the Dutch Rhine basin (age 1-3)

The habitat suitability is mainly determined by water depth for first year sturgeon and by salinity for second year and age three plus (see Fig. 4.1, Fig. 4.2, Fig. 4.3). For first year sturgeon, given their tolerance for fresh water, a large area is considered potentially suitable (table 4.1, Fig. 4.1).

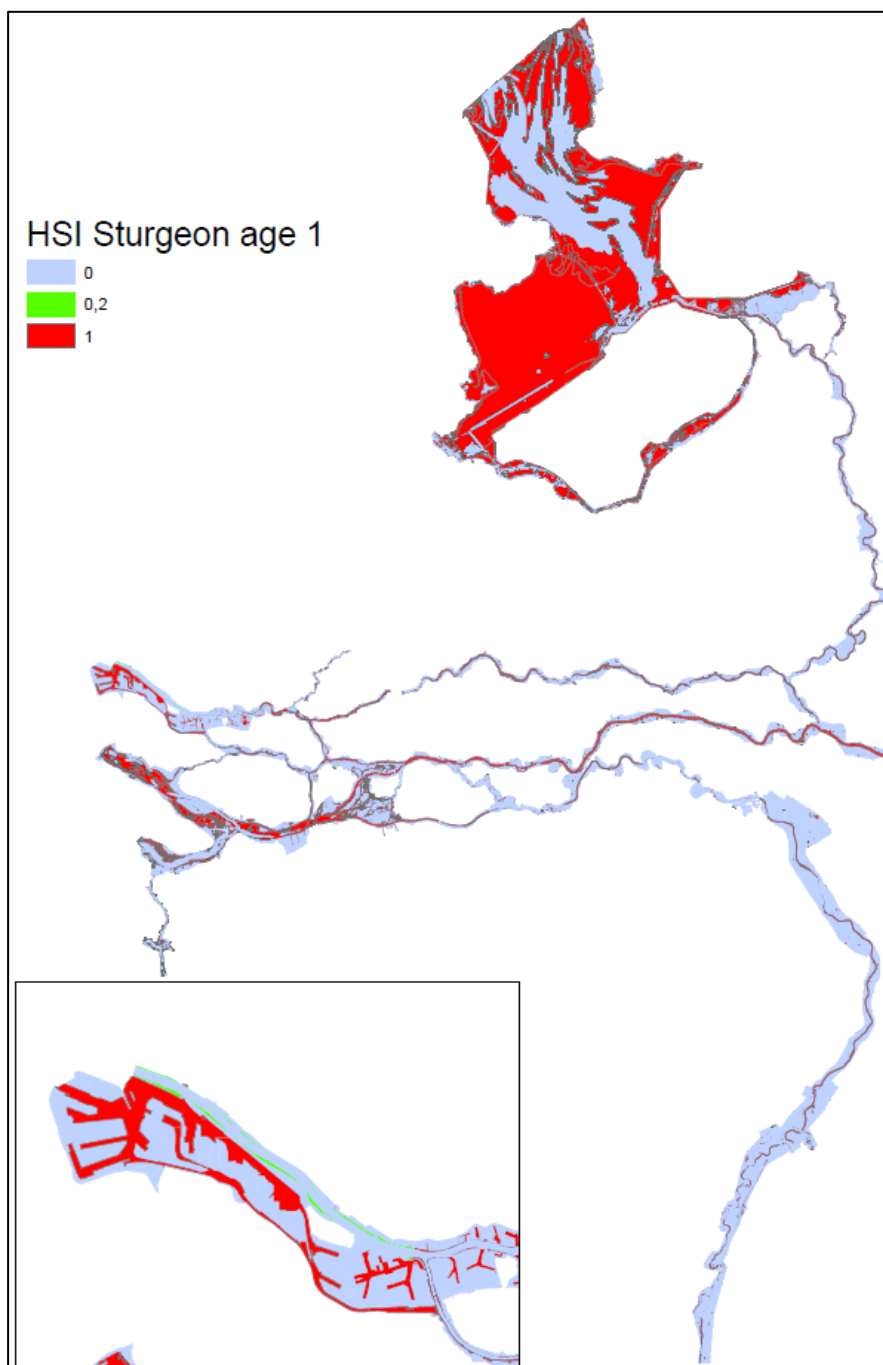


Figure 4.1. HSI index for age 1 sturgeon in the Dutch Rhine basin based on salinity and water depth. The Nieuwe Waterweg and Haringvliet area are enlarged in bottom left panel.

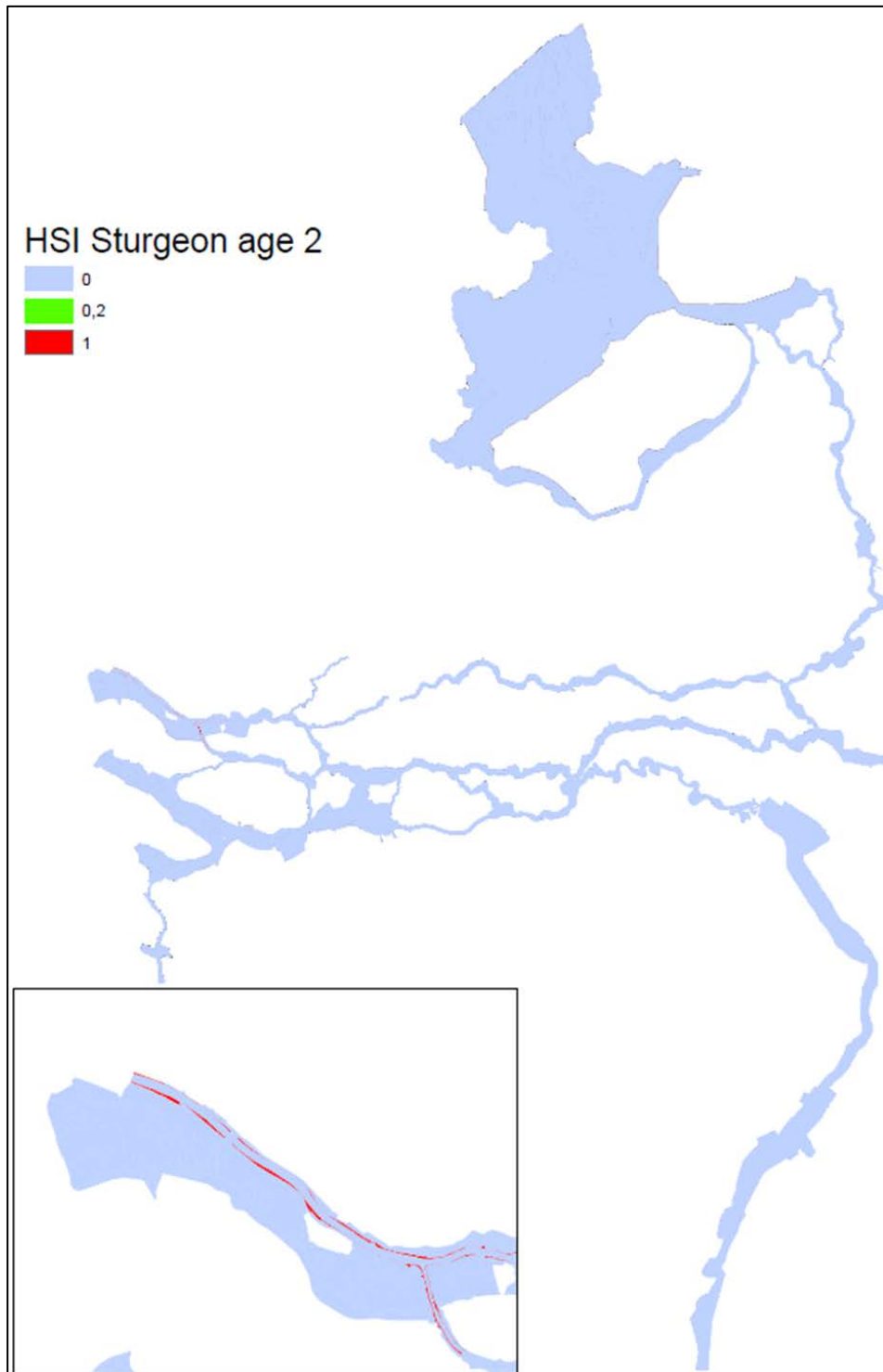


Figure 4.2. HSI index for age 2 sturgeon in the Dutch Rhine basin based on salinity and water depth. The Nieuwe Waterweg and Haringvliet area are enlarged in bottom left panel.

Especially for age 2 and 3+ sturgeon only marginal habitat can be considered suitable all situated in and along the Nieuwe Waterweg (table 4.1).

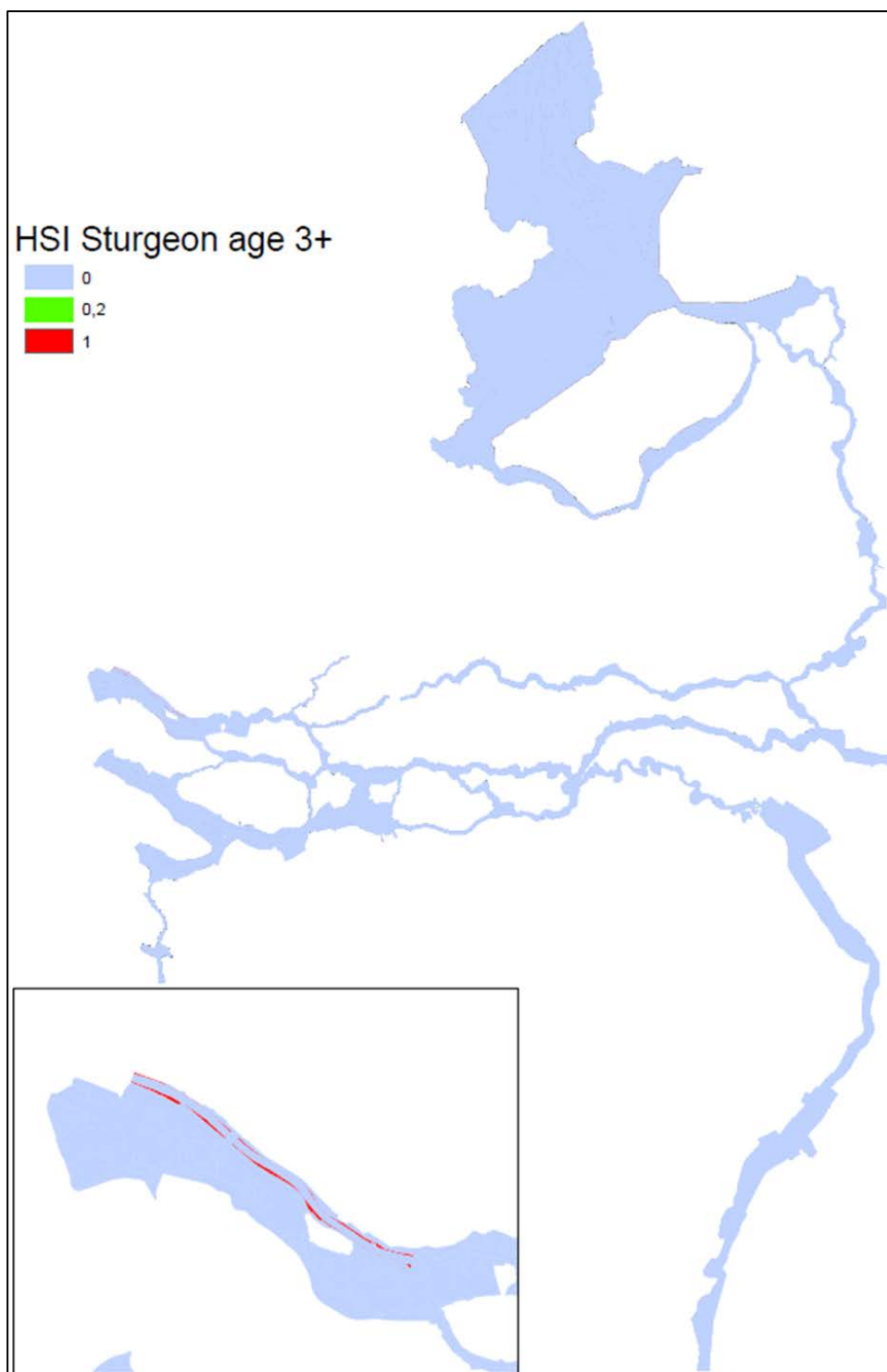


Figure 4.3. HSI index for juvenile 3+ year sturgeon in the Dutch Rhine basin based on salinity and water depth. The Nieuwe Waterweg and Haringvliet area are enlarged in bottom left panel.

Table 4.1. Area (in ha) per suitability and age class.

HSI	Age 1	Age 2	Age 3+
0	178857	364473	364620
0.2	328		
1	185759	471	325

4.2 Habitat modelling of the North Sea area (age 4+)

Maps of potential growth rates can be used as a proxy for habitat quality. The DEB model using modelled temperature data from ERSEM was run for several scenarios (1989, 2002) both during winter and summer and resulted in maps of maximum growth potential for sturgeon of 80 cm (about the size of juveniles that fully use marine habitats for growing, Fig. 4.5), and 120 cm (about the size of onset at maturity, Fig. 4.6).

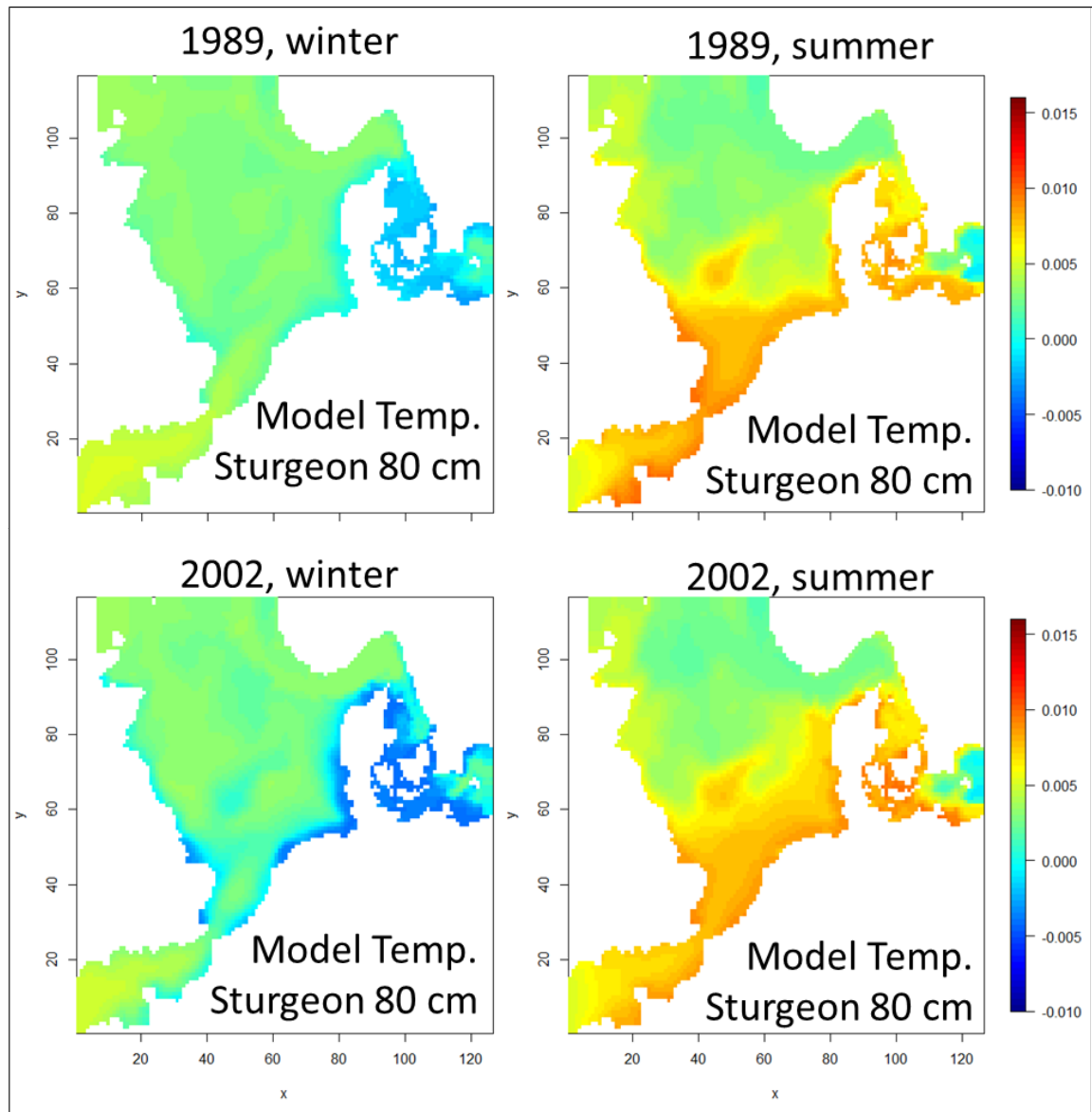


Figure 4.5. Maximum potential daily growth rates (colour scale; cm day^{-1}) of juvenile sturgeon of 80 cm based on dynamic energy budget (DEB) predictions and input from ERSEM/GOTM NIOZ (temperature) for the years 1989, day 1 (top left) and day 200 (top right) and 2002, day 1 (bottom left) and day 200 (bottom right).

For sturgeon of 80 cm, the coastal areas of the Southern North Sea and also the Doggerbank provide the highest maximum potential daily growth during summer. The Northern North Sea appears less suitable (Fig. 4.5). As could be expected, growth potential during winter given the low temperatures is low.

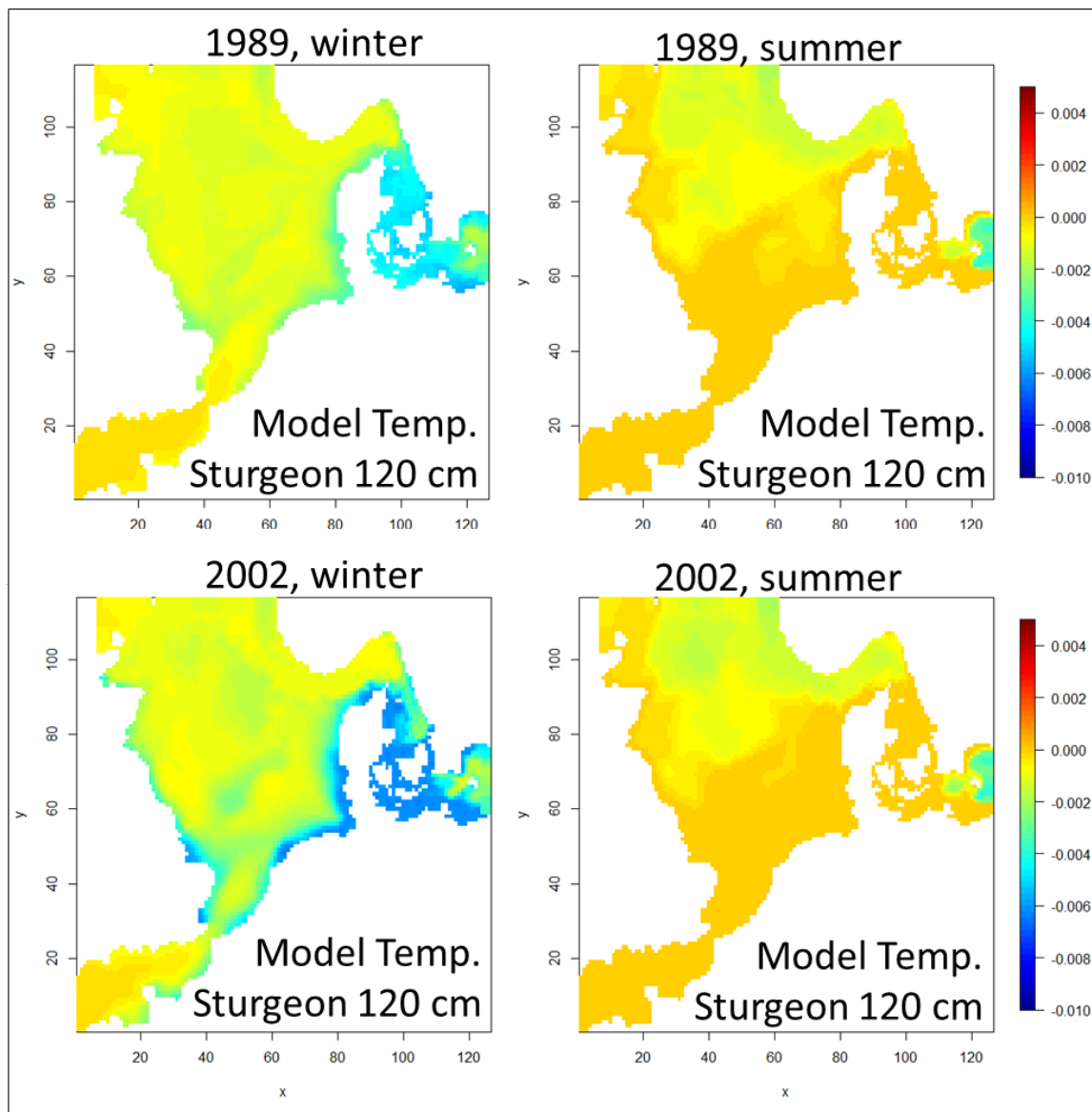


Figure 4.6. Maximum potential daily growth rates (colour scale; cm day^{-1}) of sturgeon at the onset of maturity (120 cm) based on dynamic energy budget (DEB) predictions and input from ERSEM/GOTM NIOZ (temperature) for the years 1989, day 1 (top left) and day 200 (top right) and 2002, day 1 (bottom left) and day 200 (bottom right).

For sturgeon of 120 cm the areas where the highest maximum potential daily growth rate can be reached are more evenly distributed in the southern North Sea (Fig. 4.6) when compared to juveniles of 80 cm (Fig. 4.7).

In addition to model runs on existing datasets, we also performed model runs with data from temperature models taking into account future climate change. For 2049 we ran a DEB-model using temperature as a base for both winter and summer. The area for which the model was run is somewhat larger than could be used for the 1989 and 2002 datasets, enabling comparison to e.g. the coastal areas directly North from the Gironde. These runs resulted in maps with the projected maximum potential for sturgeon of 80 cm (Fig. 4.7), and 120 cm (Fig. 4.8) during the year 2049.

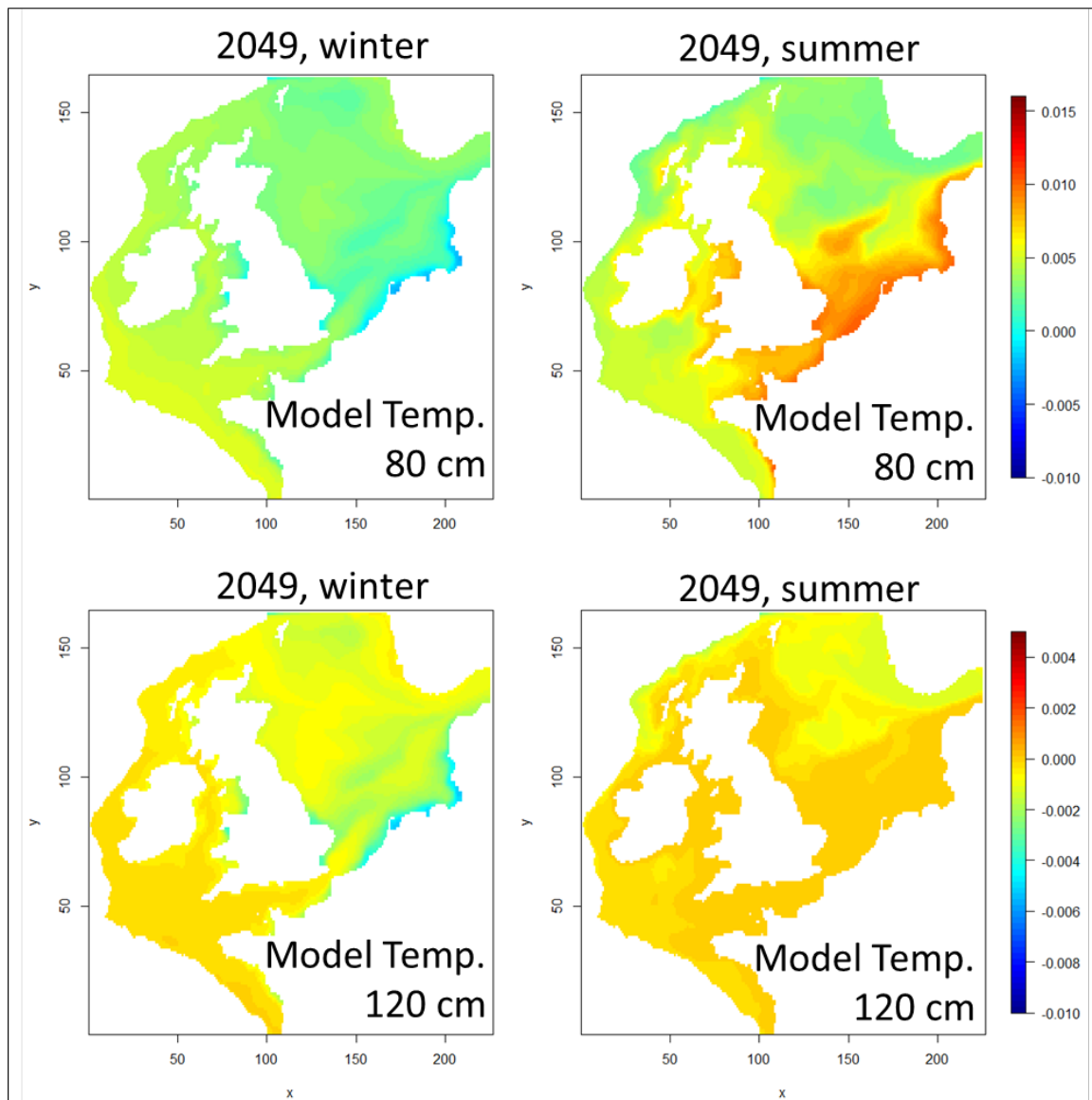


Figure 4.7. Maximum potential daily growth rates (colour scale; cm day^{-1}) of juvenile sturgeon of 80 cm (top panels) and 120 cm (bottom panels) based on dynamic energy budget (DEB) predictions and input from ERSEM/POLCOMS PML (temperature) for 2049, day 1 (top left) and day 200 (top right) and 2002, day 1 (bottom left) and day 200 (bottom right).

The projected future maximum potential daily growth rate in 2049 shows that especially for juvenile sturgeons (80 cm) the coastal areas of the southern North Sea houses the largest areas of optimal growth in the entire region that was considered. For sturgeons at the onset of maturity (120 cm) the pattern is less clear and they can reach maximum growth rates across larger areas.

DEB-models based on temperature work well given that food is not limiting. When food conditions are less than optimal, the maximum potential growth rate will be lower than predicted from temperature alone. For the years 1989 and 2002 data was also available on benthic productivity which can be used as a proxy for food availability for sturgeons. This enabled DEB-models to be run again using both temperature and food conditions for several scenarios (1989, 2002) both during winter and summer. This resulted in maps of maximum growth potential for sturgeon of 80 cm (Fig. 4.8), and 120 cm (Fig. 4.9).

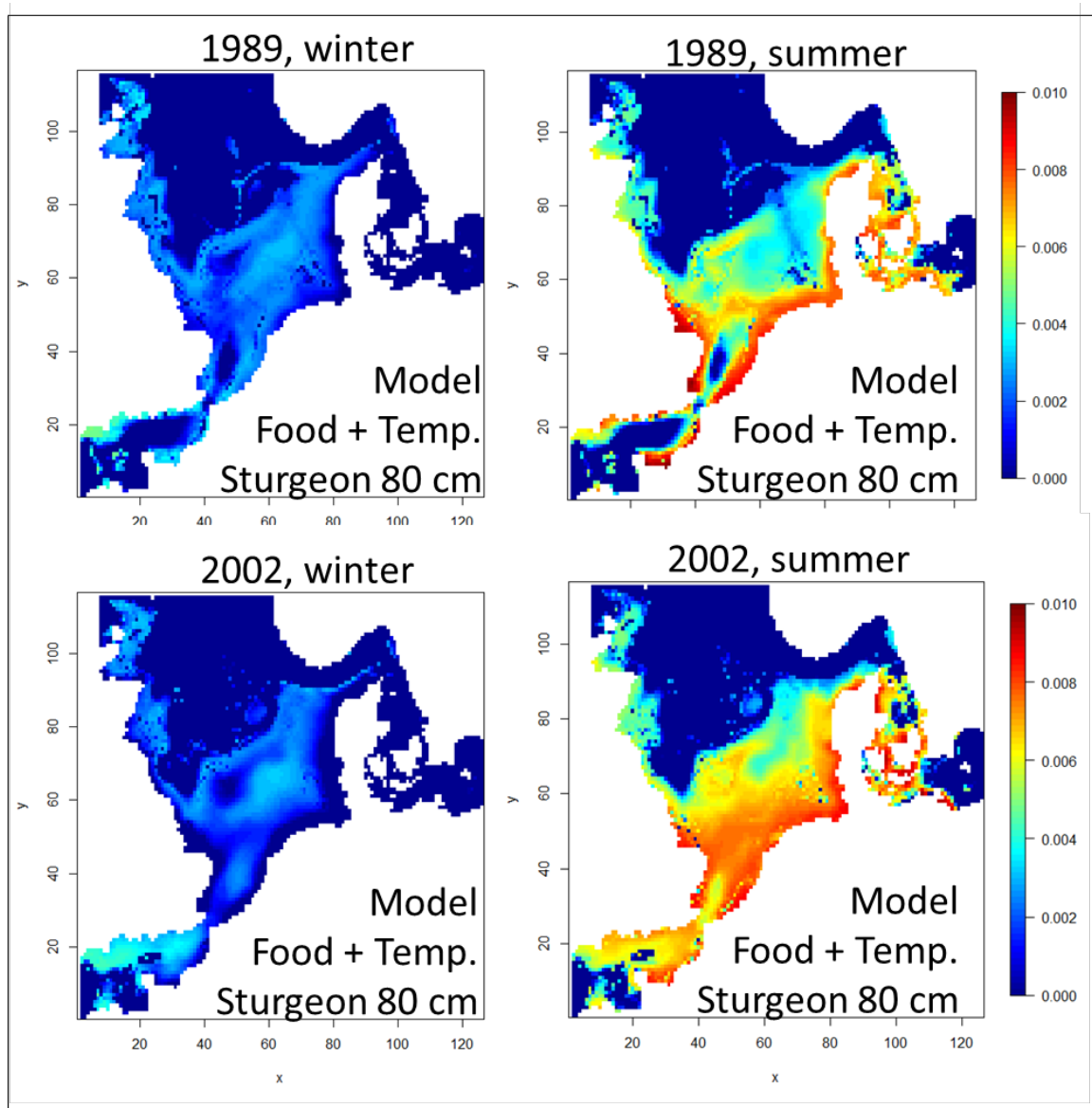


Figure 4.8. Maximum potential daily growth rates (colour scale; cm day^{-1}) of juvenile sturgeon of 80 cm based on dynamic energy budget (DEB) predictions and input from ERSEM/GOTM NIOZ (temperature and benthic production/food) for the years 1989, day 1 (top left) and day 200 (top right) and 2002, day 1 (bottom left) and day 200 (bottom right).

The DEB-model based on temperature and benthic productivity shows an even more profound importance of the coastal areas in the Southern North Sea, which is again more prominent for juveniles of 80 cm in both the summers of 1989 and 2002. However, also for the sturgeons of 120 cm the coastal areas, especially the Dutch delta and German bight, show higher maximum potential daily growth (Fig. 4.9) than when based on temperature alone (Fig. 4.6).

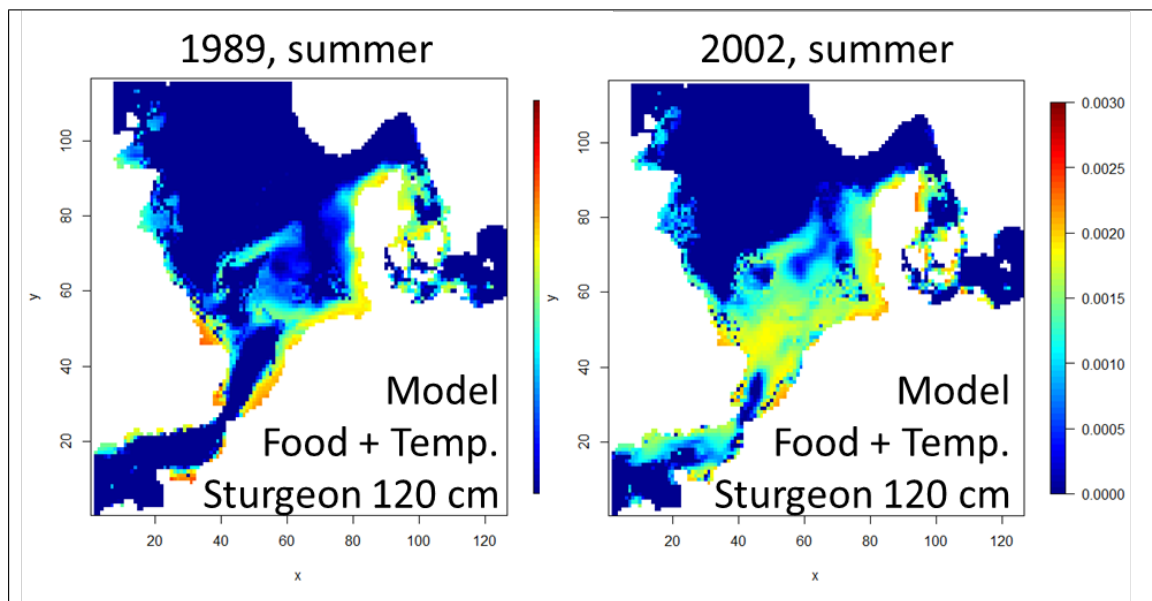


Figure 4.9. Maximum potential daily growth rates (colour scale; cm day^{-1}) of sturgeon at the onset of maturity (120 cm) based on dynamic energy budget (DEB) predictions and input from ERSEM/GOTM NIOZ (temperature and benthic production/food) for the years 1989, day 200 (left) and 2002, day 200 (right).

For benthic production no projected future datasets are available and therefore the DEB-model for sturgeon could not be run based on temperature and benthic production for the year 2049.



Close up of a European sturgeon at a life stage that uses marine habitats (Photo Bram Houben).

5 Spatial overview of migration barriers and fisheries

5.1 Migratory barriers and connectivity in the Rhine basin

For adult sturgeon migrating from sea into the Rhine basin in the current situation, only the Nieuwe Waterweg can be considered to be freely passable without physical barriers. At the Haringvliet and Afsluitdijk sluices passage is at least hampered and limited to small migratory windows during discharge events (Fig. 5.1).

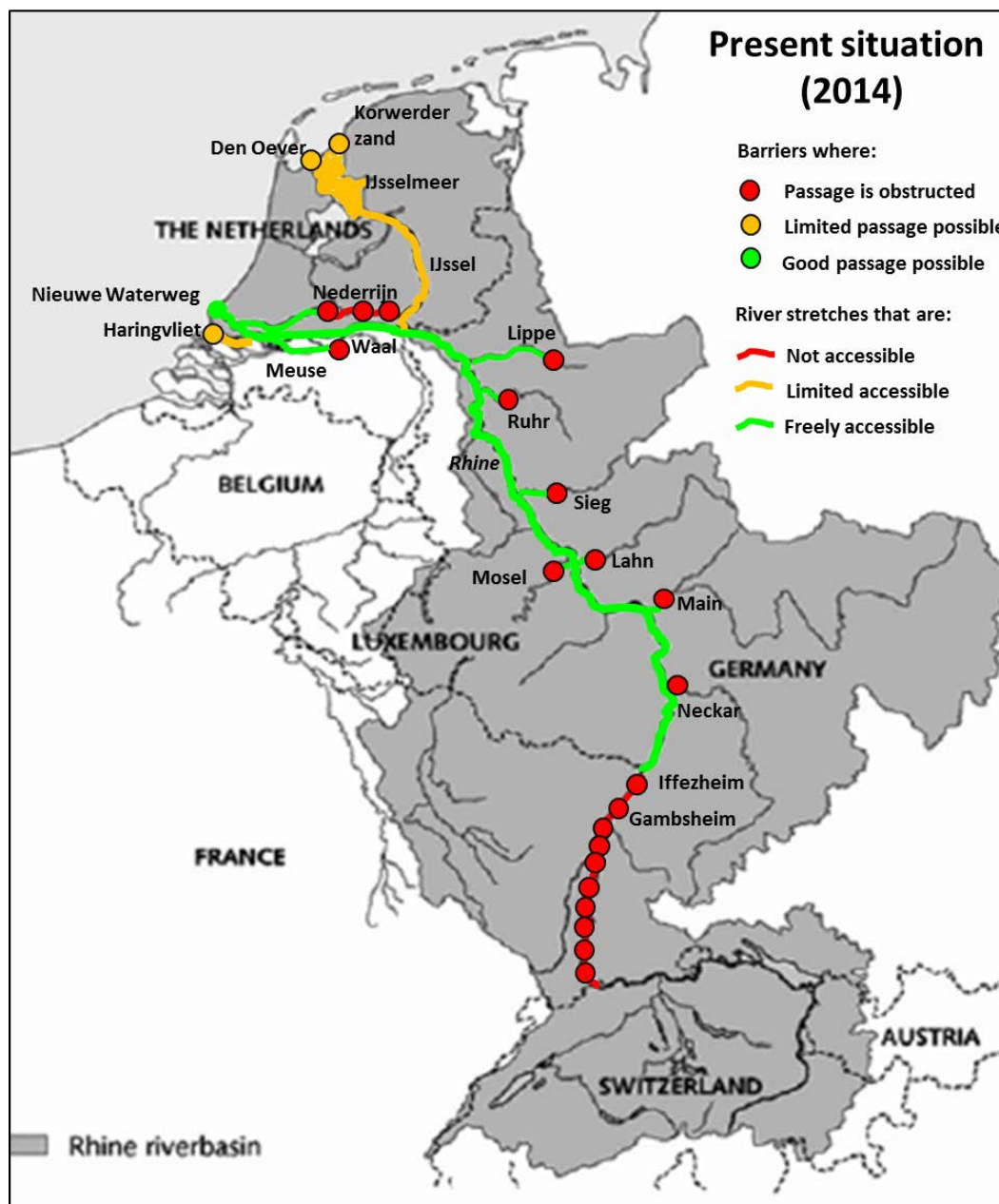


Figure 5.1. Upstream passage along the migration barriers in the main river system and the accessibility of river stretches for upstream migrating adult sturgeons in the present situation (2014).

The slots in the fishways in the Nederrijn branch are too narrow for passage of adult sturgeon (see table 3.4) and they will probably not pass through the small surface layer overflowing the fishway crest (Parsley *et al.* 2007). The fishways at Iffezheim and Gamsheim are long technical fishways in which the vertical slots are too narrow for adult sturgeon passage (Fig. 5.1).

In the near future, the 'Haringvliet op een Kier' measure will result in practically unhampered passage at the Haringvliet sluices, except in rare situations with extremely low river discharge. The proposed Fish Migration River passage at Kornwerderzand in the Afsluitdijk will probably provide sturgeon good passage possibilities at Kornwerderzand. At Den Oever, the fish passage that is constructed in 2014 will not be suitable for passage of adult sturgeon, though fish friendly sluice management could provide some more migratory opportunities than in the current situation (Fig. 5.2).

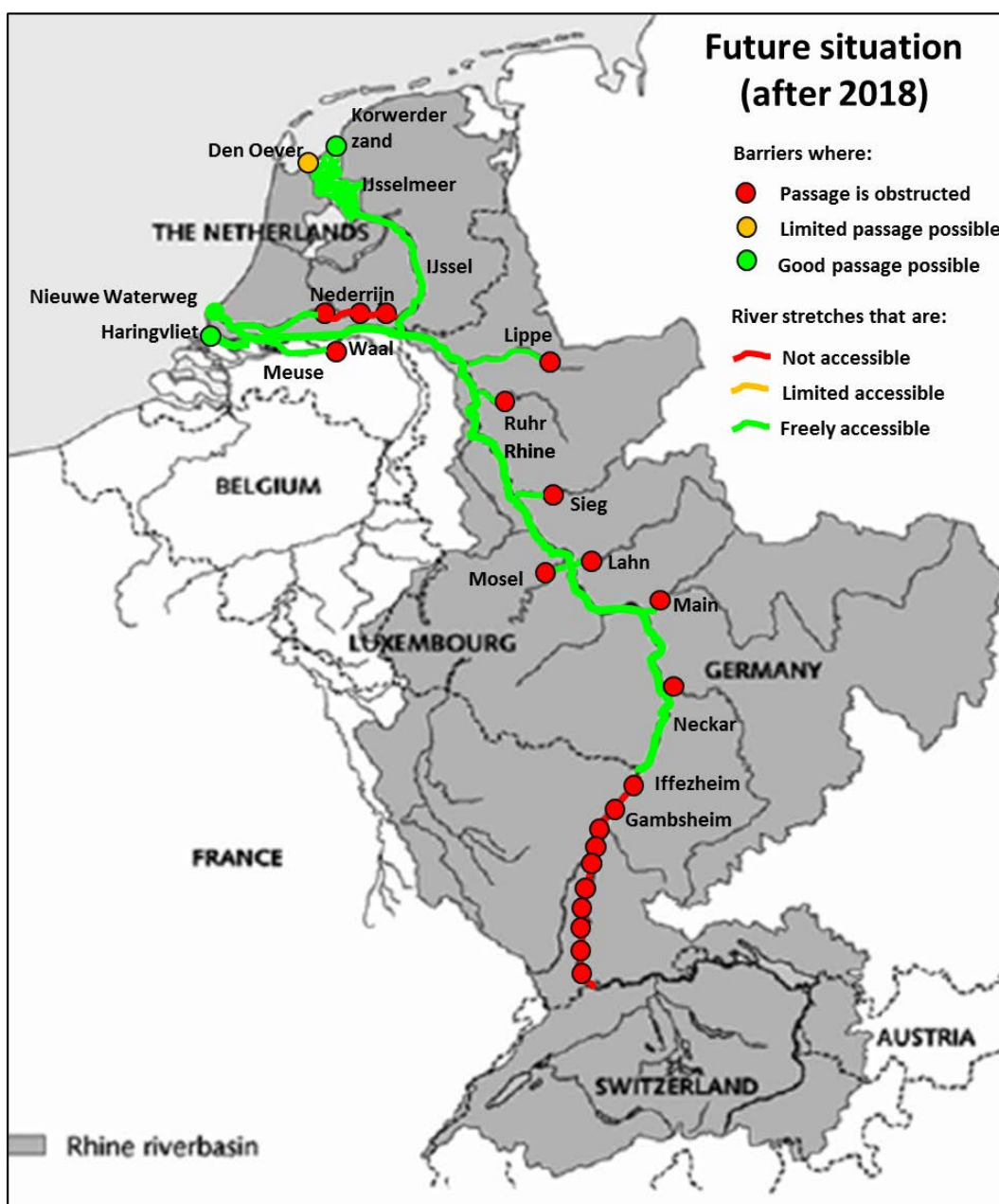


Figure 5.2. Upstream passage along the migration barriers in the main river system and the accessibility of river stretches for upstream migrating adult sturgeons in the future situation (after 2018).

None of the existing fishways in the main stem, branches or tributaries appear to be suitable for successful passage of adult sturgeons of up to 3 m length. In most cases the dimensions of pools, orifices or vertical slots are too small to facilitate the swimming movements of large sturgeons or only shallow overflowing water is available for passage, which appears to be unfavourable for sturgeon passage.

In most tributaries, only a small section from the mouth of the tributary to the first barriers can be accessed, except for the Meuse, Lippe and Sieg where relative larger stretches of 10s of km are accessible.

Because in the near future all three entrance routes to the Rhine are freely accessible, Nieuwe Waterweg, Haringvliet and Afsluitdijk at Kornwerderzand presumably provide good passage opportunities to adult sturgeons, a large section of the Rhine up to Iffezheim and small sections of the tributaries are accessible (green section in Fig. 5.2). In the Lower Rhine in the Netherlands the Waal (discharges ca. 70 % of average Rhine flows) and IJssel (discharges ca. 10 % of the average Rhine flows) branches are without migration barriers. Only the Nederrijn branch (discharges ca. 20 % of average Rhine flows) has a series of three weir-shiplock-fishway complexes that probably severely hamper upstream passage of adult sturgeons. Whether the accessible section of the Rhine basin contains sufficient spawning habitat is still unknown and beyond the scope of this study.

5.2 Spatial distribution and intensity of fisheries in the southern North Sea

Based on a continuous restructuration of positions of fishing vessel with Vemco Positioning System (VPS) and given the large fraction of the fleet covered with VPS-data, it is possible to produce maps of fishing intensity (hours present) for the different fisheries. On request of marine organisation OSPAR, The International Council for Exploration of the Sea (ICES) produced maps with fishing intensity for the most important fisheries of fleets of all countries (ICES, 2014). Here we present the demersal fisheries that are more likely to interfere with benthic feeders as sturgeons than pelagic fisheries.

In Fig. 5.4 an overview is given for the intensity of beam trawls larger than 12 m, demersal seiners, otter trawls and dredgers during the most recent year for which maps were available, i.e. 2012 (ICES, 2014).

Beam trawl fisheries is most intensive in the southern North Sea and especially along the Belgian, Dutch and German coast. These fisheries include both beam trawling for flatfish, mainly targeting sole and plaice, and smaller trawlers beam trawling for shrimps. Demersal seining fisheries are more intensive in the English Channel and North-West from Denmark than in the southern North Sea. Otter trawling is most intensive in the northern North Sea, the English Channel and the French coast of the bay of Biscay, but much less in the southern North Sea. Dredging fisheries are mainly concentrated in the English Channel and offshore from Scotland. Hardly no dredging fisheries take place in the southern North Sea.

For the Dutch fleet IMARES has more detailed VPS data available. With these, the beam trawl fisheries could be categorized in large beam trawlers, targeting mainly flatfish such as sole and plaice, and smaller beam trawlers targeting mainly shrimps. The VPS data reflecting fishing intensity in hours averaged over three years 2010-2012 categorized in larger and smaller beam trawlers is plotted in Fig. 5.5 (IMARES, unpublished data).

The larger Dutch beam trawlers fish most intensively in the more central open water of the southern North Sea, whereas the smaller Dutch beam trawlers, mainly shrimp fishers, fish predominantly in the Dutch and German coastal zones (Fig. 5.5).

In addition to this, also some fisheries not covered by the ICES 2014 overview such as the gillnet fisheries could be plotted. The gillnet fisheries of the Dutch fleet are concentrated along the Dutch coast (Fig. 5.5). Gillnet fisheries of other countries might do the same, so fishing intensity directly along the German and Danish coasts are presumably also present.

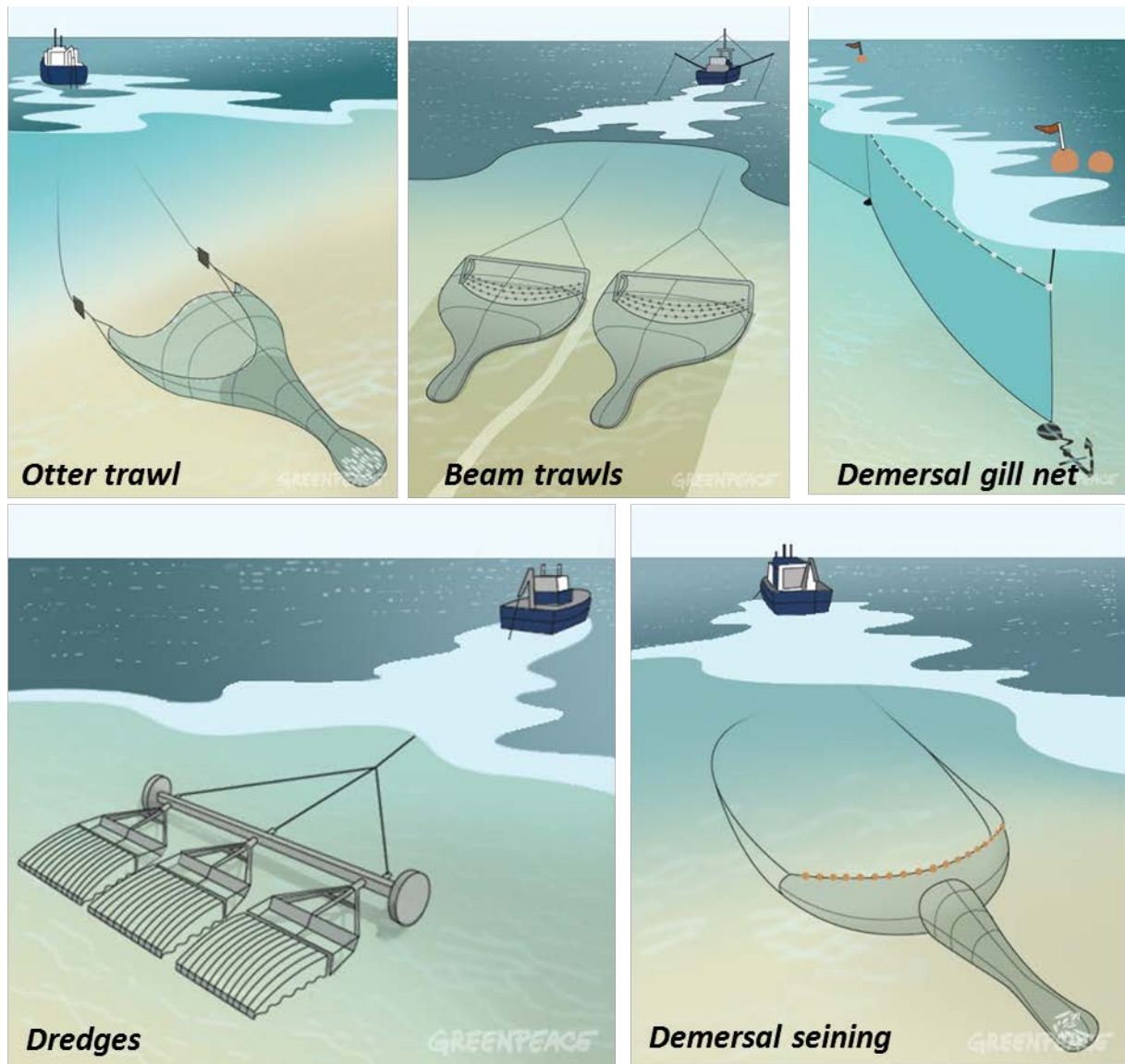


Figure 5.3. Illustration of the different fishing gears and techniques as mentioned in the text and presented in Figs. 5.4 and 5.5. (Source: <http://www.greenpeace.org>).

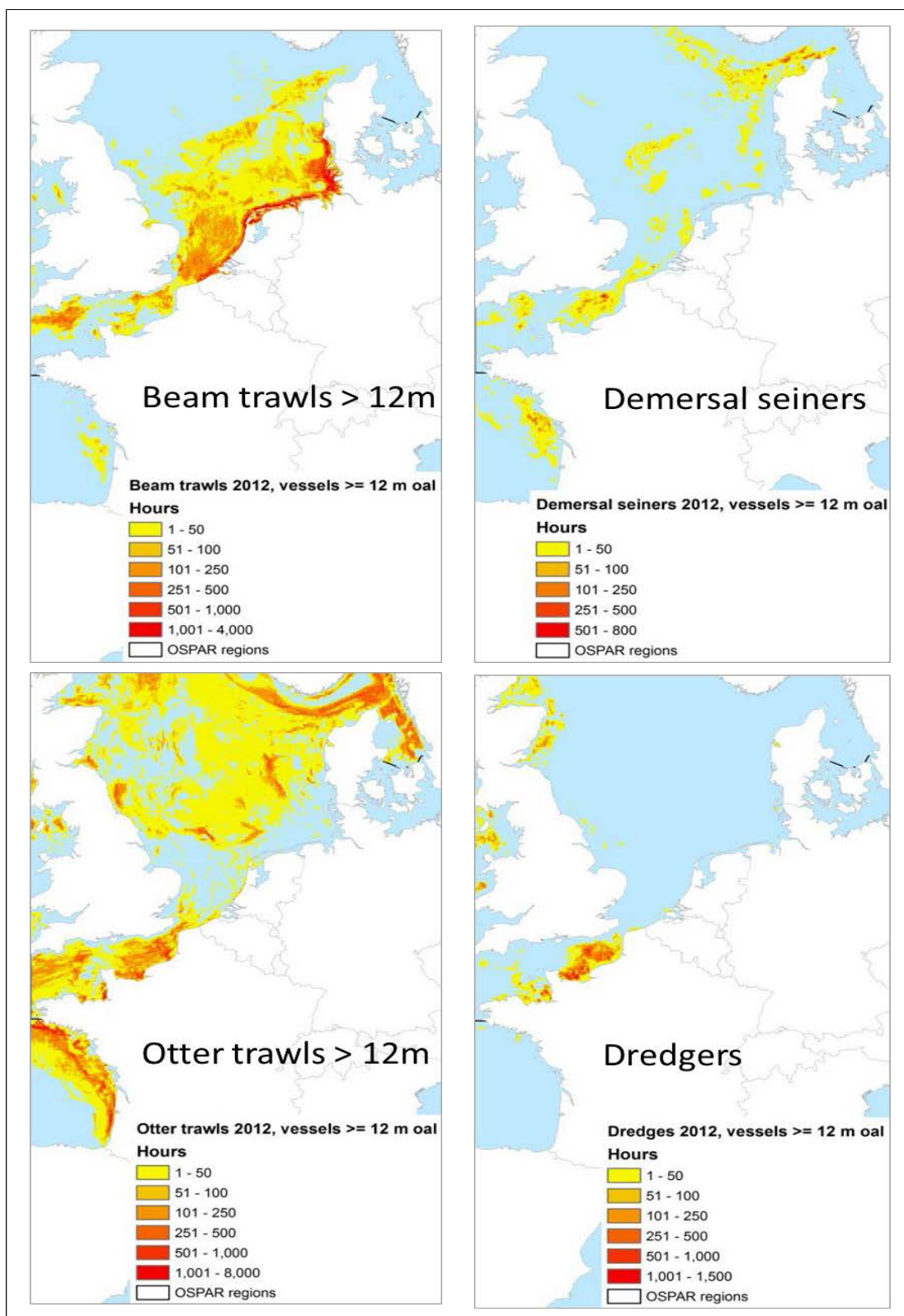


Figure 5.4. Effort by the four main fisheries near the bottom in the OSPAR regions. Note that the colour scale is not linear (ICES, 2014).

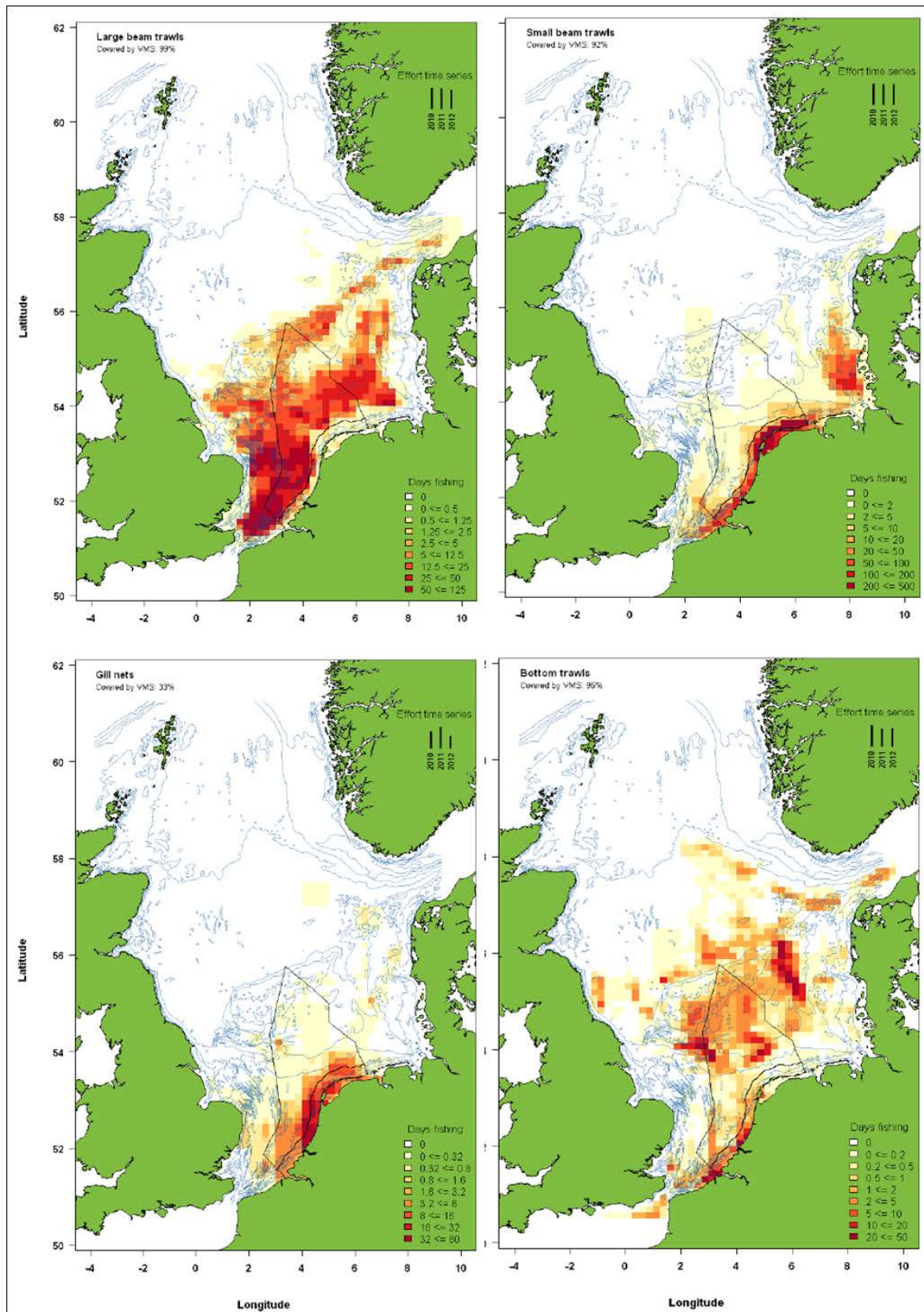


Figure 5.5. Fishing intensity based on VPS-data during 2010-2012 of the Dutch fleet of four different types of fisheries: large beam trawlers, small beam trawler, gill netting and bottom trawling.

6 Discussion and conclusions

6.1 Habitat quality assessment of the Rhine and Southern North Sea

Because the European sturgeon severely declined and disappeared in most of its distribution area long before field research on habitat requirements could be done, not much is known on habitat use and requirements. Relatively most is known on the habitat use of juvenile European sturgeons in the Gironde estuary during their 2nd and 3rd year (Age 2 and 3), but data on habitat use and requirements is very scarce during their 1st year (age 1) and during the marine stages of older juveniles and adults (Williot *et al.* 2011). This severely hampers the possibilities to model habitat suitability and validation of the models of the current and near future situations during the different life stages for areas where sturgeon has disappeared in the past.

Freshwater and brackish habitat quality

Given the lack of habitat requirement data of European sturgeon as mentioned above, we used an approach including salinity and water depth preferences for the freshwater and estuarine stages (Age 1-3). These were found in the Gironde estuary, a dynamic and tidal system. Whether juvenile sturgeons show the same preference for water depths in more stagnant waters like lake IJsselmeer and Haringvliet and running freshwater branches of the Lower Rhine remains unknown. Thus, the area indicated to be suitable for sturgeons during their first year should be regarded as a maximum estimate, that becomes smaller depending on how strict they are with respect to other habitat and food requirements.

If this is also true for other systems than the Gironde and juvenile sturgeon are dependent on brackish estuarine waters during part of their juvenile stages (mainly 2nd year and 3rd year), it is clear that the scarcity of estuarine waters in the Rhine delta severely limits the habitat quality, based on salinity requirements alone. Also in future scenarios with more extreme variants of the Haringvliet sluice regime, the area that is suitable for growth during the second and third year remains limited. How well the brackish very small and dynamic unnatural area of brackish habitat in the Nieuwe Waterweg branch will serve as a suitable growing habitat is unknown.

In addition to this, also connectivity plays a role in locating these brackish growing habitats since they are only present in one of the three river branches flowing to sea. When young sturgeons move downstream to brackish habitats after the first year, following the river flow will result that the largest part of the juveniles will reach the Nieuwe Waterweg branch, a smaller fraction will reach the Haringvliet branch and an even smaller fraction will reach lake IJsselmeer. Whether they are capable of performing large scale search behaviour necessary to locate the small areas of suitable brackish habitats remains to be seen.

Thus, if sturgeon age 2 and 3 do need brackish estuarine habitats, both the scarcity of brackish habitats and that they are only present in one of the branches, would be an important bottleneck for the opportunities of a successful future reintroduction.

However, recent studies in the Elbe river indicate that juvenile European sturgeon move to more marine habitats already after the first growing season (Gessner, unpublished data). This suggests that one year old juvenile European sturgeons might be more flexible in what habitats they use for growing during their 2nd and 3rd year than is apparent from the Gironde area and that marine habitats may serve as feeding grounds. In addition, when 2nd and 3rd year juvenile sturgeons would also be able to use the freshwater lakes such as IJsselmeer and Haringvliet, in the Gironde there are no large eutrophic freshwater lakes present, this might provide good feeding opportunities as well. For instance, for another

diadromous species that went extinct in the Rhine basin, the North Sea Houting *Coregonus oxyrhynchus*, it was found that after reintroduction in the 1990s, lake IJsselmeer proved to be a very good growing habitat for both juveniles and adults (Borcherding *et al.* 2008). And that this species was less dependable on estuarine and marine habitats than thought on forehand based on knowledge from small Danish river systems. To find out if juvenile European sturgeons are flexible in using either freshwater habitats for longer periods than in the Gironde or on the other end might leave for marine habitats much earlier than in the Gironde, can only be determined when the Rhine basin is stocked with young 1st year sturgeons.

Food availability in fresh and brackish waters of the Dutch Rhine basin

Most macrofauna data that is collected in the larger water bodies in the Dutch Rhine basin is for monitoring, where ecological quality of the sampled water bodies is indicated by e.g. species richness and species occurrence (van Diepen & Verdonshot 2001). Data on densities of macrofauna in high spatial resolution are not readily available in overviews or maps. From the literature overview it is apparent that juvenile sturgeons mainly feed on benthic invertebrates in and on soft sediments. In the discussion below, we focus on the benthic invertebrates other than bivalves, which do not form part of the diet of sturgeons.

Studies in the lower Rhine branch Waal, Biesbosch, Hollandsch Diep, Haringvliet showed that macroinvertebrate densities were low in the 1960s and 1970s, but increasing thereafter and are considered high since the 1990s as a result of the improved water quality (Wijnhoven & Hummel 2008). In the 2000s, in Haringvliet and Biesbosch especially worms (mainly *Tubificidae* and chironomid larvae, Schmidt *et al.* 2013) and Hollandsch Diep mainly chironomid larvae were abundant in high densities (Wijnhoven & Hummel 2008). In the lower sections of the Waal, Meuse and Nederijn-Lek down to the Nieuwe Waterweg chironomid larvae, molluscs and amphipods (mainly *Corophium multisetosum*) were abundant (Wijnhoven & Hummel). Results from a macrofauna study in the Waal at the Gamerensche Waarden indicated that the densities of benthic invertebrates, mainly worms, chironomid larvae and molluscs, was much lower in the groyne fields of the mainstream than in the three secondary channels present at that location (Bij de Vaate *et al.* 2007). In lake IJsselmeer, benthic invertebrate densities were high and mainly consisted of worms (Oligochaeta) and especially in the areas closer to shores chironomid larvae, and directly along the shoreline also amphipoda (Noordhuis 2001).

The diet of juveniles of other species of sturgeon that use freshwater during the first year(s) consist mainly of chironomid larvae and amphipoda in sterlet *Acipenser ruthenus* in the Danube (Djikanovic *et al.* 2015); insect larvae formed 97 % of the diet lake sturgeon *Acipenser fulvescens* in the Winnipeg River (Barth *et al.* 2013) and chironomid larvae, amphipoda and molluscs in lake sturgeon in the Saint Lawrence River (Nilo *et al.* 2006); mainly chironomid larvae, amphipoda and molluscs in shortnose sturgeon *Acipenser brevirostrum* (Usvyatsov 2012); mainly amphipoda (*Corophium* spp.) and chironomid larvae in young-of-the-year white sturgeon *Acipenser transmontana* (Muir *et al.* 2000). Since all these other *Acipenser* species show a very similar diet of soft bodied benthic invertebrates of mainly chironomid larvae, amphipoda and molluscs, it appears likely that juvenile European sturgeon, that use freshwater habitats, feed on these prey species as well. Soft bodied benthic invertebrates are abundant in especially the lower reaches of the Rhine basin, i.e. Haringvliet, Hollandsch Diep, lower branches in the west of the Netherlands and lake IJsselmeer. In the faster flowing stretches with groyne fields such as the rivers Waal and IJssel densities of these prey items appears much lower, and can mainly be found in higher densities in side channels or perhaps connected backwaters.

Marine habitat quality

Due to the lack of data on many parameters needed for the DEB modelling, we used a DEB model that was made for a related *Acipenser* species sterlet (*A. ruthenus*) and then adjusted this to European sturgeon. It is possible to build a DEB model that is better adjusted to European sturgeon than used in

this desk study, but that requires more extensive modelling and parameterizing than could be performed within this study. Nevertheless we are confident that the maps reflect relative growth potential of the marine habitats in the North Sea region fairly well. The absolute growth rate predicted in this study might be different, given that we only had the growth rate of one individual to validate it for.

The DEB modelling the North Sea area indicates good habitat quality for growing of juveniles and adult sturgeon in the southern North Sea and more specifically the coastal areas for juvenile sturgeons. Both in temperature, and temperature plus food DEB modelling. The relative habitat quality will likely only improve given current climate scenarios. It is therefore unlikely that habitat quality of the southern North Sea will act as a bottleneck in the case of a future reintroduction of the European sturgeon in the Rhine (and Elbe) basin(s).

Densities of soft bodied benthic invertebrates are high in most coastal areas in the southern North Sea, e.g. at the outlet of the Haringvliet and Voordelta, an area directly west from the Rhine delta (Wijnhoven & Hummel 2008). The rapid growth of the recaptured European sturgeon from the Elbe in the mouth of the Westerschelde confirms that feeding conditions are good in the marine coastal areas of the southern North Sea (Brevé & Houben 2014).

6.2 Human impact and bottlenecks for sturgeon

In this section we briefly discuss the findings of this study in light of different human impact factors and whether they pose potential bottlenecks for future reintroduction of European sturgeon in the Rhine.

Migration barriers and connectivity between habitats

Connectivity between growing, wintering and spawning habitats for adult sturgeon are foreseen to be fairly good for entering the Rhine system in the near future. The Haringvliet dam will be periodically opened during most of the tides after 2017 providing good passage possibilities, especially during periods with larger river flow. The passage of the Afsluitdijk will likely improve especially at Kornwerderzand when the Fish Migration River and a more fish friendly discharge regime will be incorporated in the near future (Winter *et al.* 2014).

In the Nederrijn, one of the three lower Rhine branches, however, upstream migration of sturgeons is likely to be hampered. Whether adult sturgeons are able to and/or willing to pass the relatively small surface layer of overflowing water in the three V-stepped passes in the Nederrijn (Hagestein, Amerongen, Driel) is questionable. The vertical slot in the bottom half of each step in the pool type fishways is too narrow for passage for adult sturgeon.

In the upstream part of the Rhine, the mainstream up until Iffezheim will be accessible for sturgeon. The vertical slot pool type fishways at Iffezheim and Gamsheim will be unsuitable for passage of large adult sturgeons due to the small size of the pools and narrow widths of the vertical slots between pools. Thus, potential suitable spawning grounds more upstream Iffezheim up to Basel are not available for European sturgeon. The same holds for the main tributaries of the Rhine that all have migratory barriers with fishways that are all too small dimensioned to facilitate adult sturgeon passage. Whether this is a bottleneck for sustaining a future sturgeon population in the Rhine basin depends then on the area of suitable spawning area that is available downstream from Iffezheim. The spawning habitat quality and distribution of suitable spawning habitat for European sturgeon within the Rhine basin is still unknown.

Improving these fishways to make them suitable for passage of adult sturgeons of up to 3 m might be very costly given the wide dimensions fishways need to have (see section 3.3). Whether this is necessary for a successful reintroduction of the European sturgeon in the Rhine basin depends on whether the

spawning habitat that is currently available and accessible (the green area in Fig. 5.2.) is sufficient and whether a reduced success in upstream migration through the Nederrijn branch is limiting for the upstream passage success of adult sturgeons reaching the spawning grounds. Both can be studied before or during reintroduction using test adult sturgeons and study their upstream migration behaviour and success and assessment of sustainable spawning areas in relation to connectivity. Thus the eventual modifying of fishways can be tackled later on and only when this proved to be a limiting bottleneck and only at the specific fishways proved to restrict sturgeon connectivity.

The downstream migration along the barriers in the Lower Rhine is relatively unhampered since they can move with the discharged water over the weirs or through the sluices. At present, only at the weir-complex at Amerongen there is a hydropower station that may cause extra mortality for downstream movement of juvenile sturgeons. The adult sturgeons will not be able to pass the 10 cm wide openings of the trash racks in front of the hydropower station. At Hagestein there is a smaller hydropower plant that is out of order at present but might be put in operation again in the future. Even though downstream migration is hardly unhampered, the connectivity between upstream spawning habitats and scarcely present or even absent brackish habitats in the downstream parts of the different Rhine branches is hampered when sturgeons follow the river flow and do not perform large scale searching behaviour. In addition to this, juvenile sturgeons might concentrate upstream from these barriers which make them more vulnerable to predation. Predation rate of juvenile sturgeons is already high in natural situations, which is reflected by the very high fecundity of adult sturgeons (millions of eggs per spawning event and many spawning events during its long adult lifespan).

Fisheries

Given its longevity and very late maturing, extra mortality due to unnatural causes such as fishing (either targeted catch as in the past or untargeted bycatch in other fisheries) is often indicated to be an important factor when reintroducing sturgeons (Gessner *et al.* 2010, 2011, Williot *et al.* 2011). Fishing intensity in the North Sea area is high (Fig. 5.1 and Fig. 5.2). This is confirmed by the pilot stocking and tagging experiment of 43 juvenile sturgeons in the Lower Rhine, where six (14 % of the released sturgeons) were reported to be caught along the Dutch coast (Breve *et al.* 2014). The actual percentage of bycaught sturgeon will most likely be higher since not all recaptured might be reported and the number of sturgeons that reaches the North Sea will be lower than 43 (at least one is known to have died before migrating to sea but the telemetry data suggest that more sturgeons did not reach the sea, Fig. 2.2, Breve *et al.* 2014). All bycatches were within the small beam trawl fishery and very close to the coastline (Fig. 2.3). Since sievenets were obliged within the shrimp beam trawl fisheries, no further bycatches of sturgeons were reported, indicating that the sievenets that allow escape of larger fish would lower the catch rate of sturgeons. The observed pattern in only bycaught sturgeons close to the coast is in accordance with both the DEB modelling results (Fig. 4.5 and Fig 4.8) showing highest habitat quality for sturgeons of 80 cm close to the Dutch and German coast, and also with the distribution of the fishing intensity of small beam trawlers mainly targeting shrimp (Fig. 5.2). For a more extensive discussion on this see Breve *et al.* (2014).

When comparing the fishing intensity maps of the different fisheries and the habitat quality maps from the DEB modelling, the small beam trawl fishery and gill net fisheries are likely to most severely interfere with sturgeon during the juvenile stages. For the shrimp fisheries, the recaptures of tagged sturgeons confirm this. For the gillnet fishery, as of yet, no recaptures were reported. This might be due to a lower catch rate in these gear type possibly because they can evade these gears, or it might be due to an underreporting of bycatches in gillnets and that they do occur.

For adult sturgeons that perform much wider migratory distribution and uses a wider range of marine habitats, potential interference can occur with more fisheries. However, on the habitat use and dispersal of adult sturgeon along the continental shelf, not much is known at present (Williot *et al.* 2011).

In addition to catch rate and given the high fishing intensity in the North Sea area, an important factor will be the survival of sturgeons after being caught. These will vary highly for the different fisheries and within fisheries can vary with how bycaught sturgeons are handled. It would be useful to incorporate findings from the French communication program (Rochard and Lepage 1996; Michelet 2011) in a River Rhine and North Sea Action Plan.

Commercial fisheries in the freshwaters of the Rhine basin have been much reduced. Fishing intensity is highest in Lake IJsselmeer with fykenet fishing during December-August (closed during September-November) and gillnet fisheries. In other parts of the flowing branches of the Rhine basin fykenet fishing is banned since 2010 due to high levels of dioxin in eel.

To minimize impact of fisheries on European sturgeon several measures or mitigations can be taken:

- Banning potentially harmful fishing gears, i.e. with high catch rates and low survival rates of European sturgeon.
- Spatial and/or temporal closing of fisheries, i.e. when catch rates are high during certain periods in the year and/or certain areas ('hotspots') for European sturgeon.
- Lowering catch rates by providing selective escape devices in fishing gears, for instance the escape flaps in beam trawls targeting shrimps, or selectively deterring sturgeons from fishing gears (no examples for this are yet available).
- Maximizing survival in fisheries where good survival can be achieved by careful handling and releasing procedures. For this, fishermen need good instructions and have sufficient incentives to do this. Systems based on regulations alone and therefore need to be reinforced by control are usually less successful.

Shipping

The Rhine is one of the most intensively shipped waterways in the world, especially the Waal branch which is the most important migratory branch for both adult and juvenile sturgeons. Extra mortality is possible due to vessel-strike. One of the 43 juvenile sturgeons released in the Rhine was found a week later, dead on a river bank. The sturgeon was not preserved by the finder. From the given description and as can be seen on the provided photograph the fish was decapitated and already dead for a few days (Breve *et al.* 2014). Also other studies in North America indicate vessel strike and hitting by propellers as a possibly important source for unnatural mortality (Brown & Murphy 2010).

Climate change

The DEB modelling for temperature shows that the projected climate change may result in an increased relative habitat quality for juvenile sturgeons in the coastal areas of the southern North Sea. This offers possibilities and may increase the relative importance of the Rhine basin for saving the sturgeon in the wild. The climate change scenario of the marine growth potential in the North Sea fits well with the expected importance of the Rhine basin for spawning under projected future climate change that indicates that the relative importance of the Rhine basin for spawning will be higher in the future (Fig. 6.1, Lasalle *et al.* 2010, 2011).

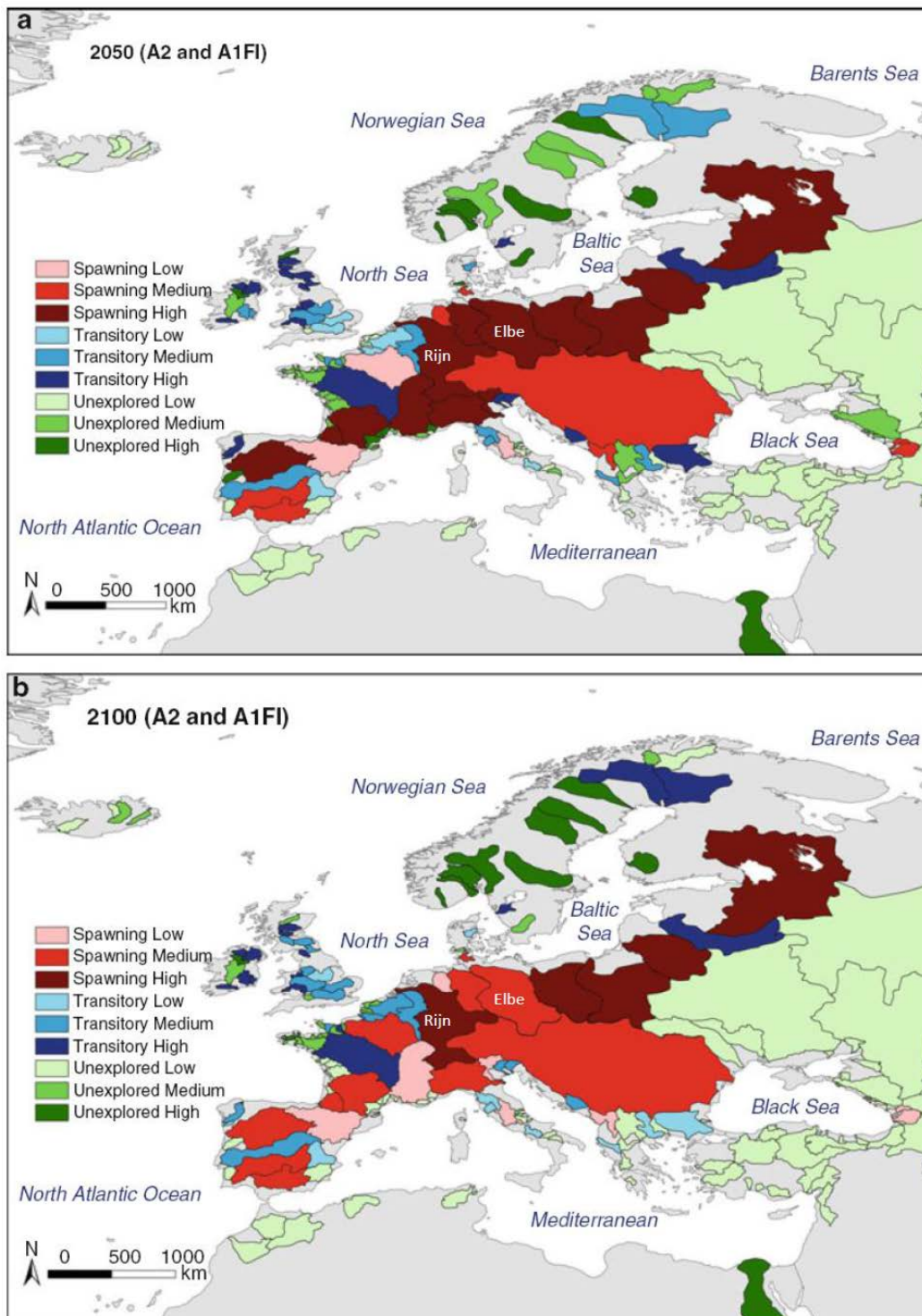


Figure 6.1. Projected spawning habitat quality of river basin for European sturgeon in 50 to 100 years due to expected climate change (from Lasalle et al. 2011 modified by de Kok & Meijer 2012).

Increasing occurrence of exotic sturgeons

Next to the above mentioned human impact also other factors play a role, such as the increasing occurrence of exotic sturgeon species in the Rhine and also Elbe basin. This may lead to competition or hybridization with future reintroduced European sturgeons. Moreover, these species might convey exotic diseases or parasites to the Rhine basin and southern North Sea. Whether this is truly a problem is

difficult to determine in the absence of an existing population of European sturgeons. Fact is that in eastern Europe many sturgeons species coexisted in the same river systems, e.g. in the Volga River six different sturgeon species are native. It is however better to take an precautionary approach and avoid, e.g. by using only non-fertile hydroid sturgeons in the garden pond trade and therefore lowering the risk that escaped or released exotic sturgeons form a potential problem.

Was the Atlantic sturgeon native to the Rhine and coexisted with the European sturgeon?

It is noteworthy that there is increasing evidence that the European sturgeon coexisted with the Atlantic sturgeon *A. oxyrinchus* in a wider area in western Europe than previously thought (e.g. restricted to the Baltic) and that this species is very likely to have been indigenous for the River Rhine basin as well (Chassaing et al. 2013).

6.3 Conclusions on future opportunities for sturgeon in the Rhine

- Knowledge on habitat use and requirements of the European sturgeon is limited and is especially scarce for juvenile 1st year and adult stages. This hampers the possibilities in estimating and validating habitat quality in river basins and marine areas.
- If juvenile European sturgeons need brackish estuarine habitats during part of their life-cycle, e.g. during their 2nd and 3rd year as the Gironde data suggest, then the lack of estuarine and brackish habitats in the lower sections of the Rhine basin are important bottlenecks for especially juvenile sturgeons. Foreseen future scenarios in the Haringvliet are most probably insufficient to lower this population bottleneck. However, if juvenile European sturgeons are more flexible in selecting either marine habitats at an earlier stage already after the first growing season as preliminary results from the Elbe suggest or if they can remain feeding in the downstream sections of the freshwater systems in the lower Rhine, e.g. the large freshwater lakes Haringvliet, Hollands Diep and IJsselmeer then the scarcity of brackish estuarine habitats in the future Rhine system proves to be less restrictive for a successful reintroduction of European sturgeon in the Rhine basin.
- If juvenile European sturgeons have a similar diet and food preference as other *Acipenser* species that use freshwater systems, i.e. soft bodied benthic invertebrates (mainly chironomid larvae, amphipoda, molluscs and worms) that live in and on soft sediments, then good food conditions are currently present in the lower sections of the Dutch Rhine basin, e.g. Haringvliet, Hollands Diep, lower parts of the Waal and Nederrijn branches and IJsselmeer. The faster flowing river stretches with groyne fields appear less favourable, and here good food conditions might be limited to specific non-mainstream habitats e.g. flowing side channels or connected backwaters.
- Upstream connectivity is at present hampered at at least two of the three possible inlets to the Rhine basin. After 2018 it is foreseen that this will be improved greatly at the Haringvlietdam and Afsluitdijk at Kornwerderzand.
- The Nederrijn branch contains three barriers with fishways that appear unsuitable for the passage of large adult sturgeons. The main migration route via the Waal is freely accessible and also the IJssel. The impact of the lower passability of the fishways in the Nederrijn depends on the relative use of this route and whether large scale searching behaviour will occur.
- Upstream, adult sturgeon can freely access the mainstream of the Rhine basin up to Iffezheim and most tributaries are only accessible for a maximum of several kilometres (Ruhr, Mosel, Main, Lahn and Neckar) or up to several tens of kilometres (Meuse, Lippe and Sieg). There, barriers with fishways unsuitable for passage of adult sturgeons of 2-3 m restrict further upstream movement. Whether this

is a problem for a future successful reintroduction of European sturgeon depends on whether the area of the Rhine basin that is accessible to upstream migration contains sufficient spawning habitat in terms of spawning habitat quality and surface area of spawning grounds.

- Downstream migration for adult sturgeons is hardly hampered within the area that is freely accessible for upstream migration. Only in the Nederrijn branch hydropower station(s) are present that pose a potential threat to part off the downstream migrating juveniles. Adult sturgeons cannot pass the trash racks in front of the hydropower station.
- Indirectly, connectivity of downstream migrating juveniles following the flow of the different Rhine branches may interfere with the limited availability of brackish habitats in only part if the lower sections of the River Rhine basin or increased predation risk directly upstream of discharge sluices or weirs may lead to concentrations of juvenile sturgeons, which make them more vulnerable to predation by predatory fish or birds.
- Growth potential and habitat quality of the marine habitats in the southern North Sea appear to be good, also in comparison with other adjacent areas, and especially in the coastal zones for juvenile sturgeons. Food availability along the coastal areas of the southern North Sea is high for sturgeons.
- Future climate change may probably enhance the relative importance of the marine areas in the Southern North Sea, even more so in combination with a projected increased importance of the Rhine basin for spawning of European sturgeon.
 - Fisheries in the southern North Sea are intense and very likely an important bottleneck in future reintroductions of European sturgeons. The coastal oriented small beam trawlers targeting shrimps are conflicting with the best growing habitats used by juvenile sturgeons. It is noteworthy that after sievenets were obliged in shrimp beam trawls, allowing escape of larger fish, no bycaught sturgeons were reported anymore. In general, lowering fishery mortality can be achieved by either minimizing catch rates, or by maximizing survival rates after catch. The protection of the European sturgeon can only be achieved in cooperation with professional fisherman.

Recommendations

- At present it is unknown whether spawning habitats are available in the present Rhine basin for European sturgeon of sufficient quality and surface area. An assessment of the available suitable spawning areas in the present Rhine basin in relation to the connectivity is needed to address whether additional habitat improvement is needed or some barriers need to be made suitable for passage of adult sturgeon.
- How well juvenile sturgeons of age 1-3 can use either more marine habitats just downstream from the Rhine delta or the downstream freshwater sections of the Dutch Rhine basin is not known currently. This can be studied by following the faith and habitat use of released test individuals of juvenile sturgeons of less than one year old. In addition to this, if detailed information on local habitat use becomes available from these proposed test fish release studies, then a more detailed study of available macrofauna data can be carried out to relate local food availability to habitat selection.
- Because fishing mortality is an important potential bottleneck to the success of future reintroduction programs of European sturgeon it is essential to make an inventory and assessment of finding mitigation measures to minimize fisheries mortality. For this, experiences with European sturgeon and

fisheries in the Gironde system can be taken into account, or best practices in other fisheries and sturgeon species. Also an impact assessment of the different fisheries in the southern North Sea can then be carried out. This can include different possible fishery management options, socio-economic approaches in cooperation with fishermen.

- There are many potential opportunities, threats and unknowns for the reintroduction of European sturgeon listed in this study and other reviews. A desk study to prioritise these different factors might better facilitate future choices and allocation of efforts and funding during the next steps towards implementing a reintroduction program of European sturgeon.

7 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Will European sturgeons of these sizes roam the Dutch coastal waters again in the future?

9 Justification

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The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Ir. O.A. van Keeken
Researcher



Signature:

Date: 9-4-2015

Approved: Drs. J.H.M. Schobben
Head of Department Fish



Signature:

Date: 9-4-2015